



This is a digital copy of a book that was preserved for generations on library shelves before it was carefully scanned by Google as part of a project to make the world's books discoverable online.

It has survived long enough for the copyright to expire and the book to enter the public domain. A public domain book is one that was never subject to copyright or whose legal copyright term has expired. Whether a book is in the public domain may vary country to country. Public domain books are our gateways to the past, representing a wealth of history, culture and knowledge that's often difficult to discover.

Marks, notations and other marginalia present in the original volume will appear in this file - a reminder of this book's long journey from the publisher to a library and finally to you.

Usage guidelines

Google is proud to partner with libraries to digitize public domain materials and make them widely accessible. Public domain books belong to the public and we are merely their custodians. Nevertheless, this work is expensive, so in order to keep providing this resource, we have taken steps to prevent abuse by commercial parties, including placing technical restrictions on automated querying.

We also ask that you:

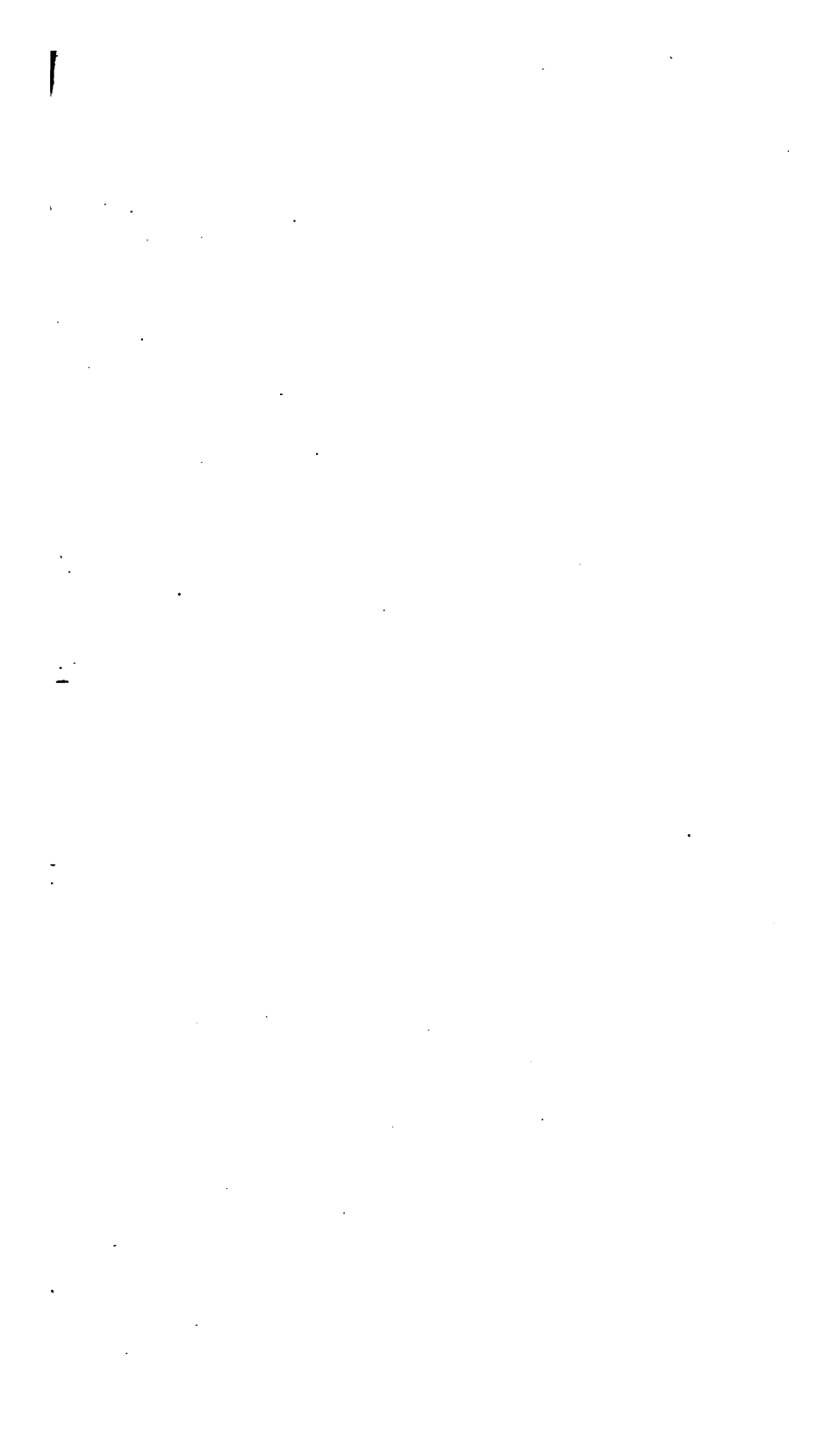
- + *Make non-commercial use of the files* We designed Google Book Search for use by individuals, and we request that you use these files for personal, non-commercial purposes.
- + *Refrain from automated querying* Do not send automated queries of any sort to Google's system: If you are conducting research on machine translation, optical character recognition or other areas where access to a large amount of text is helpful, please contact us. We encourage the use of public domain materials for these purposes and may be able to help.
- + *Maintain attribution* The Google "watermark" you see on each file is essential for informing people about this project and helping them find additional materials through Google Book Search. Please do not remove it.
- + *Keep it legal* Whatever your use, remember that you are responsible for ensuring that what you are doing is legal. Do not assume that just because we believe a book is in the public domain for users in the United States, that the work is also in the public domain for users in other countries. Whether a book is still in copyright varies from country to country, and we can't offer guidance on whether any specific use of any specific book is allowed. Please do not assume that a book's appearance in Google Book Search means it can be used in any manner anywhere in the world. Copyright infringement liability can be quite severe.

About Google Book Search

Google's mission is to organize the world's information and to make it universally accessible and useful. Google Book Search helps readers discover the world's books while helping authors and publishers reach new audiences. You can search through the full text of this book on the web at <http://books.google.com/>









THE NEW YORK
PUBLIC LIBRARY

ASTOR, LENOX
TILDEN FOUNDATIONS

PT

Fig. 1.



Fig. 7.

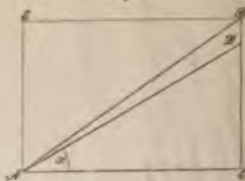


Fig. 2.

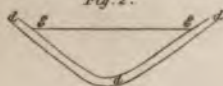


Fig. 3.

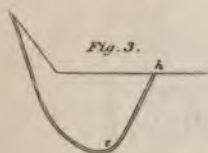


Fig. 4.

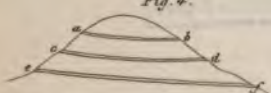


Fig. 8.

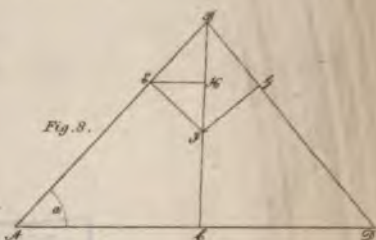


Fig. 9.



Fig. 5.

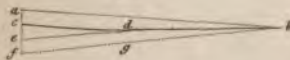


Fig. 10.

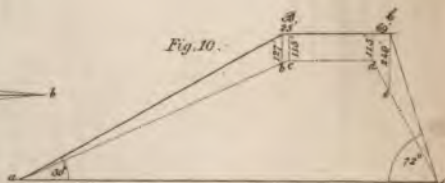


Fig. 6.

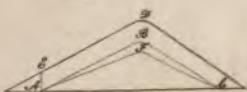


Fig. 11.



PHYSICAL, CHEMICAL, AND GEOLOGICAL
RESEARCHES
ON THE
INTERNAL HEAT OF THE GLOBE.

BY
GUSTAV BISCHOF, Ph.D.,
PROFESSOR OF CHEMISTRY AND TECHNOLOGY IN THE
UNIVERSITY OF BONN.

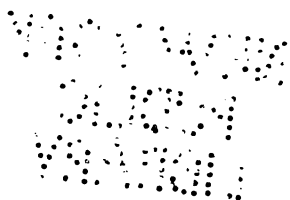
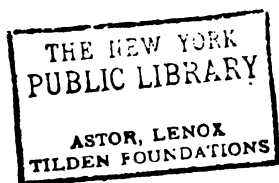
IN TWO VOLUMES.

VOL. I.
WITH A PLATE AND WOODCUTS.

LONDON:
LONGMAN, ORME, BROWN, GREEN, AND LONGMANS.

MDCCCLXI.

PTN



PREFACE BY THE AUTHOR.

SEVEN years ago the Society of Sciences of Harlem proposed the following question :

“ Plusieurs expériences, faites dans les années dernières en *Europe* et en *Amérique*, par rapport à la température intérieure de la terre, paraissant indiquer une augmentation de chaleur en raison de la profondeur, on désire une revue et un examen critique de ces expériences, afin de déterminer si l'on doit en conclure qu'une chaleur plus forte existe au centre de la terre, ou bien, si l'augmentation de chaleur, observée dans les expériences mentionnées, peut être expliquée soit par la compression et le courant de l'air dans les mines, soit par d'autres causes ? Jusqu'à quel point ces recherches peuvent-elles suffire pour expliquer l'origine des sources chaudes et des phénomènes volcaniques, ainsi que d'autres changemens que subit la terre à sa surface ? ”

I undertook to answer this important question, and was fortunate enough to succeed in obtaining the prize offered by the Society for the best treatise on the subject. Having continued and extended my researches, I published a German work entitled, “ *Die Wärmelehre des Innern unsers Erdkörpers, ein Inbegriff aller mit der Wärme in Beziehung stehender Erscheinungen in und auf der Erde, etc.* Leipsic, 1837.” In the mean time an English gentleman, and former pupil of mine, Mr Alexander Mornay, feeling an interest in

the subject of my work, undertook to translate it into English. This translation was communicated by my valued friend, Mr Leonard Horner, to Professor Jameson, with a view to its being published in the Edinburgh New Philosophical Journal. I consider it, however, necessary to state, that the Chapters from I. to XX. can alone be considered as a close translation. Indeed, upon pursuing my inquiries, and learning the facts established since that time by other naturalists, and applying them in support of my own views, I could not fail to be led to make various improvements and additions. I have accordingly remodelled the translations of Chapters XXI. and XXII., and I flatter myself that I have enriched them by many improvements and additions. My English publication may therefore be considered in some degree as a new edition of my German work.

Professor Jameson having had the kindness to revise my papers with a view to the correction of any grammatical errors, I feel the less hesitation in venturing to offer them to the English public. The errata have chiefly arisen from the reduction of the temperatures calculated in my manuscript from the scale of Reaumur to that of Fahrenheit.

I have added a table of contents, and a complete index to this volume. The latter will enable the reader to refer to the different subjects treated of.

A very short interval will, I trust, elapse before I shall be able to present the second volume to the public.

Bonn, July 21. 1840.

*** Although the author intends to publish a second volume on similar subjects to those contained in this one, yet the present treatise is to be regarded as an independent and complete work.

CONTENTS OF THE FIRST VOLUME.

PART I.

What Thermometrical circumstances on the surface of the Earth lead us to assume that an increase of Temperature towards the centre of the Earth must take place? . . . Page 1

CHAP. I. On the Circumstances under which Warm Springs are found on the surface of the earth, and on their frequency of occurrence, ... 2

CHAP. II. Can the elevated Temperature of Acidulous Springs be a consequence of the absorption of Carbonic Acid Gas? , ... 8

CHAP. III. Can the Heat of Thermal Springs be the result of Chemical Processes, or of local circumstances? and can Local Circumstances cause any modifications in the Temperature of Thermal Springs? 15

CHAP. IV. Can Springs convey Heat from the interior of the Earth to the surface? 27

CHAP. V. The Temperature of Springs being a function of that of the Meteoric Waters, and of the strata of the earth through which they flow, it is required to determine whether the variations of the temperature of the Meteoric Waters also shew themselves in Thermal Springs, ... 31

CHAP. VI. Can the Mean Temperature of a place be determined from the Temperature of Springs? and is the Mean Temperature of the Soil the same as that of the Air? 34

	Page
CHAP. VII.—Do the Rains and Meteoric Waters cause greater variations in the Temperature of the Soil than in that of the Air ?	49
CHAP. VIII.—To what depth in the Crust of the Earth does the influence of the external Temperature continue to be felt ?	57
CHAP. IX.—Can it be maintained with certainty that the Glaciers are melted from underneath by the internal Heat of the Earth, and what Thermometrical Phenomena accompany Glaciers in general ?	64
CHAP. X.—The frozen Soil of Northern Siberia is no contradiction to the increase of Temperature towards the interior of the Earth, ...	95
CHAP. XI.—The decrease of Temperature in the waters of the Sea and of Lakes, is not contradictory to the hypothesis of an increase of Temperature towards the centre of the Earth. On the contrary, we can only explain the Temperature of Sea and of Lakes by admitting an increase of temperature towards the centre of the Earth, ...	97

PART II.

Are the Observations hitherto made in Mines sufficient to determine the Law of the increase of Temperature towards the centre of the Earth ?	117
CHAP. XII.—What influence do the Meteoric Waters exert on the internal Temperature of the Earth ?	117
CHAP. XIII.—What influence have Thermal Springs on the Temperature of the interior of the Earth ?	119
CHAP. XIV.—What influence has the Air on Observations of Temperature in Mines ?	121
CHAP. XV.—What influence has Climate on the progression of the increase of Temperature towards the centre of the Earth ?	124

	Page
CHAP. XVI.—The unequal power of conducting Heat, possessed by different Rocks, causes differences in the progression of the increase of Temperature towards the centre of the Earth	125
CHAP. XVII.—Can the increase of Temperature towards the interior of the Earth follow the same Law in all parts of the Earth, departing from points all situated in the same level?	127
CHAP. XVIII.—To what proportion to the height above the lowest points of the Earth's surface is the decrease of the Temperature of the Air and of the Soil? and is this decrease the same at all parts of the Earth?	150
CHAP. XIX.—What conclusions may be drawn from the observations hitherto made on the increase of Temperatures towards the interior of the Earth?	182
CHAP. XX.—Can the progression of the increase of Temperature towards the centre of the Earth be with certainty deduced from the Temperature of Artesian Springs, and the depth from which they rise?	191

PART III.

Are Volcanic Phenomena capable of a satisfactory explanation from the increase of Temperature towards the centre of the Earth, or can Chemical processes be admitted with greater probability to be the cause of Volcanic action? 199

CHAP. XXI.—The Hypothesis, which ascribes Volcanic Phenomena to intense Chemical action shewn to be untenable, ...	200
--	-----

CHAP. XXII.—The Hypothesis, which supposes the Temperature of the Earth gradually to increase towards the centre, to a red and white heat, explains in a satisfactory manner (according to the present state of Science) Volcanic Phenomena as well as Earthquakes, ...	209
---	-----

EARTHQUAKES, ...	Page 255
Farther Reasons in support of the Hypothesis which attributes Volcanic Phenomena to increased Tempera- ture of the interior, ...	267
<i>Appendix.</i>—Additional Reasons against the Chemical Theory of Volcanos, ...	295

ON THE
CAUSE OF THE TEMPERATURE OF HOT AND
THERMAL SPRINGS,

&c. &c.

PART I.

What Thermometrical Circumstances on the Surface of the Earth lead us to assume that an Increase of Temperature towards the Centre of the Earth must take place ?

WE are indebted to Alexander Von Humboldt * for an ingenious inquiry into the principal causes of differences of temperature in the earth. In one of the following chapters we shall endeavour to ascertain to what depth the influence of the external temperature which occasions those differences continues to be felt. Beyond that boundary other circumstances of temperature present themselves, which are no longer connected with the geographical and physical climates; and at certain depths, which, however, are not the same in all parts of the earth we find the same degree of temperature beneath the perpetual ice and snow of the polar regions, as under the torrid zone. That thermometrical phenomena in the interior of the earth are totally independent of all external circumstances, proves itself not only in

the earth's crust, but also in the depths of the sea and of lakes, where a temperature prevails which is equally uninfluenced by them. Quantities of water springing out of the earth at almost every point, shew themselves equally independent of the influence of the external temperature, or, at most, but slightly modified by it. The object of this part of the present memoir will be an investigation into these phenomena, and into the circumstances more immediately connected with them, which may indirectly lead us to the conclusion, that there exists in the interior of the earth a temperature which increases progressively with the depth.

CHAP. I.—*On the Circumstances under which Warm Springs are found on the Surface of the Earth, and on their frequency of occurrence.*

If we were obliged to confine ourselves to those commonly called warm or hot springs, it would be presumptuous to conclude from their temperature that of the interior of the earth in general, as they are comparatively of rare occurrence; but if we be allowed to consider every spring as warm or thermal, whose temperature exceeds, by however little, the mean temperature of the place at which it rises, we shall find that thermal springs are far from unfrequent.

It may be considered almost as a general rule, that those springs which are usually termed mineral springs exceed, more or less, the mean temperature of the place, and it must be regarded as an exception when this is not the case.

For several years I have been observing, at different seasons, the temperature of about twenty mineral springs in the vicinity of the Laacher See, and I find that even the coldest among them always exceed the mean temperature of the place by nearly 1° R. ($= 2\frac{1}{4}^{\circ}$ Fahr.) Some of them even rise to $53^{\circ}.375$ F., $57^{\circ}.875$, and $58^{\circ}.325$,* and shew a constant degree of heat. The warmest of the numerous mineral springs in the volcanic Eifel, is that of the baths at Bertrich, the temperature of which is $90^{\circ}.5$. The hot springs of Aix-la-Chapelle and Burtscheid (Borcette), attain a much higher temperature; the warmest among the latter shews $171^{\circ}.5$.

* All the temperatures given in this article are reduced to the scale of Fahrenheit.

The numerous mineral springs of the Westerwald and the Taunus Mountains, surpass the mean temperature of the place with but few exceptions. Some, as Selters, have $60^{\circ}.125$; Schlangenbad, Ems, and Wiesbaden rise even as high as $84^{\circ}.875$, 131° , and $147^{\circ}.875$. Wille* determined the temperature of thirty groups of mineral springs between the Taunus and Vogelsgebirge, and found that they must be considered as thermals, with but few exceptions. The salt springs at Sooden, near Höchst on the Main, and in the valley of the Nahe, have a temperature of $74^{\circ}.75$ and $81^{\circ}.5$, and those of Nauheim even 86° .

A great number of fresh-water springs, which rise out of the chalk formation on the western declivity of the Teutoburger Wald and the Haar in Westphalia, possess a degree of heat exceeding the mean temperature of the place. According to my observations, made in April 1833, and repeated in May 1834, on the springs of the Lippe, Jordan, Pader, and Heder, on the fresh-water springs of Gesecke, Erwitte, &c., their temperatures vary from $47^{\circ}.75$ to $59^{\circ}.25$. Those whose temperatures are near $47^{\circ}.75$, can alone be considered as being equal to the mean temperature of the place; the warmer ones are evidently thermal, and their number is not small; for example, at Paderborn, out of sixty of the springs which I observed, there are fifty whose temperatures are above 50° , and which must consequently be considered as thermal. A warm spring, lately discovered, about forty feet distant from the Lippe springs, has a temperature as high as $69^{\circ}.35$.† The temperature of the salt springs of Westphalia is between $52^{\circ}.25$ and $63^{\circ}.5$.‡

The mineral springs of other parts of north-western Germany in Hessia, Hanover, &c., for the most part also exceed the mean temperature of the place. § The salt springs in the Prussian

* Geognostische Beschreibung der Gebirgsmassen zwischen dem Taunus und Vogelsgebirge, &c. Mainz, 1828, p. 100, and fol.

† Bischof ueber die merkwürdigen Quellenverhältnisse des westlichen Abhangs des Teutoburger Waldes im neuen Jahrbuche der Chemie und Physik vol. viii. p. 249.

‡ Kollmann in "Das Gebirge in Rheinland Westphalen," von Nöggerath vol. iii. p. 56.

§ Osann's Physikal. Médicin. Darstellung der bekannten Heilquellen der vorzüglichsten Länder Europa's, part ii. 1832.

dominions between the Elbe and the Rhine have temperatures from $52^{\circ}.25$ to $62^{\circ}.175$, and for the most part have been found not to have varied during twelve years of observation.

In the Erzgebirge, in the Riesengebirge, and in the Bohemian Mittelgebirge, the temperature of the mineral springs also exceeds, in general, the mean temperature of the place. The Wiesen, or Jobsbad, near Annaberg, has a temperature of $70^{\circ}.25$; the Wolkensteiner Bad, $83^{\circ}.75$; Landeck, $66^{\circ}.375$ to $83^{\circ}.813$; Warmbrunn, 95° to $99^{\circ}.5$; Toeplitz, $79^{\circ}.25$ to $117^{\circ}.5$; and the celebrated Carlsbader Sprudel, $164^{\circ}.75$.

Moravia also offers several examples of warm springs; for instance, the sulphurous waters of Ullersdorf, which have $88^{\circ}.25$. Hot springs are very abundant in Hungary, Transylvania, Slavonia, and Croatia; the hottest of them attain $88^{\circ}.25$ to $144^{\circ}.5$. There are a great many warm springs on the Caucasus, several of which almost reach the boiling point.*

In the interior of Germany, in Bavaria, and Würtemberg, there are comparatively few hot springs, commonly so called; there are, however, many which may be considered as thermal. The Ludwigsbad, near Wipfeld, has $56^{\circ}.75$; the salt springs at Reichenhall and Kissingen, $56^{\circ}.75$ to $69^{\circ}.125$; the mineral springs at Canstadt, $63^{\circ}.5$ to $68^{\circ}.0$; the Liebenzeller Bad, $76^{\circ}.325$; and the Wildbad, $88^{\circ}.25$ to $97^{\circ}.25$. The Grand Duchy of Baden also possesses several thermal springs, among which Baden-Baden, having a temperature of $128^{\circ}.75$ to $153^{\circ}.5$, is particularly remarkable.

A great number of thermal springs are found in the Alps. In Krain, the temperature of the Toeplitza rises to $97^{\circ}.813$; that of the Baths of Montefalcone, near Trieste, to $100^{\circ}.625$. In Carinthia, the hottest is the Villacher Bad, having $79^{\circ}.25$; in Styria, the Römerbad at Tyffer, and the baths at Neuhaus, of $43^{\circ}.875$ to $98^{\circ}.825$; in the Archduchy of Austria, the sulphurous warm spring at Baden, of $83^{\circ}.75$ to $99^{\circ}.5$; Salzburg, the celebrated Gasteiner Wildbad, of $99^{\circ}.5$ to $117^{\circ}.5$.

In Tyrol thermal springs are numerous. According to the observations made, at my request, by my friend Professor En-

* Hermann Untersuchungen der Mineralquellen am Kaukasus, &c.—in the Nouveaux Mémoires de la Soc. Impériale des Naturalistes de Moscow, vol. ii. p. 387.

nemoser on about twenty-six warm springs, their temperatures fall between $52^{\circ}.25$ and $72^{\circ}.95$. Neither are they of uncommon occurrence in Switzerland; the hottest are St Gervaise, near Mont Blanc, $61^{\circ}.875$ to $97^{\circ}.925$ Pfaeffers, $99^{\circ}.5$ to $100^{\circ}.625$; Aix-les-Bains (in Savoy), $111^{\circ}.875$ to $116^{\circ}.825$; and Leuk, $97^{\circ}.25$ to $124^{\circ}.25$.*

In France, from the Pyrenees to the mountains of the Vosges, a great number of warm springs are to be met with. Among the many sulphurous springs in the department of the East Pyrenees, which are dispersed over fourteen districts, Anglada† observed the temperature of forty-two thermal springs, of which only three possess a temperature below 77° ., twelve between $77^{\circ}.0$ and $99^{\circ}.5$, ten between $99^{\circ}.5$ and $122^{\circ}.0$, fourteen between $122^{\circ}.0$ and $144^{\circ}.5$, and three between $144^{\circ}.5$ and $172^{\circ}.625$. Even the coldest among all those sulphurous springs are sensibly warmer than the neighbouring fresh-water springs, which have only $47^{\circ}.75$ and 50° of temperature.

In the volcanic mountains of Auvergne and the Vivarais, a great many thermal springs are found. The hottest of these are: Mont-Dore-les-Bains, of $113^{\circ}.0$; St. Nectaire, $65^{\circ}.75$ to $89^{\circ}.6$; Vichy, $90^{\circ}.5$ to $113^{\circ}.0$; and Chaudes Aigues, $190^{\circ}.4$.‡

As the object here is only to point out the occurrence of thermal waters in the most various formations, I think it unnecessary to mention further the hot springs of other countries, where, however, it would be easy to shew that they are to be found in equal abundance. *Vienna Hot Springs &c.*

But it is not Nature alone that furnishes us with hot springs; art can also draw them forth from the interior of the earth. Almost all artesian wells possess a temperature superior to the mean temperature of the place. Thus the temperatures of forty-eight springs bored for in and near Vienna, were found by observa-

* Robert Bakewell (Philosoph. Magazine, January 1828, p. 14 to 59), communicates some very interesting remarks on the frequent occurrence of hot springs in the district of the pennine Alps. With these we may compare the observations of Pallasou on the numerous hot springs of the Pyrenees. (Mémoire pour servir à l'Histoire Naturelle des Pyrénées, 1815, p. 435.)

† Mémoires pour servir à l'Histoire Generale des Eaux Minérales Sulphureuses et des Eaux Thermales; Paris, vol. i. p. 31 and 35.

‡ Bischof, die vulcanischen Mineralquellen Deutschlands und Frankreichs. Bonn, 1826, p. 213.

tions made in November 1830 to fall between $52^{\circ}.25$ and $57^{\circ}.2$,* whereas the mean temperature of Vienna is $50^{\circ}.81$.† At Erlangen (mean temp. between $47^{\circ}.75$ and $50^{\circ}.0$), springs of $53^{\circ}.375$ were met with in the Keuper (?) formation at depths of 168 and 99 feet.‡ At Würzburg (mean temp. $50^{\circ}.675$), an artesian well was sunk 200 feet deep, the temperature of which was $54^{\circ}.725$.§ At Nürnberg (mean temp. between $47^{\circ}.75$ and $50^{\circ}.0$), springs were discovered in the Keuper at depths of 71, 166, and 357 feet, having temperatures of $50^{\circ}.0$, $52^{\circ}.25$, and $56^{\circ}.188$; and others at 100 and 318 feet of $53^{\circ}.375$ and $54^{\circ}.5$.|| In Würtemberg a great number of artesian wells have been sunk with various success, all of which have temperatures exceeding the mean temperature of the places at which they are situated.¶ Thus eight of these wells at Berg, near Stuttgart, in the muschelkalk yielded, at depths of 117 and 163 feet, mineral waters of $65^{\circ}.75$ to $70^{\circ}.25$, very strongly impregnated with carbonic acid gas. The warmest contained a greater and the coldest a smaller proportion of gas. In another case, in the same neighbourhood, a stream of water suddenly burst forth at a depth of 98 feet, with great violence, caused by the explosion of the compressed gas. The water contained a great quantity of carbonic acid, and had a temperature of about $65^{\circ}.75$. In and about Canstadt, water strongly impregnated with carbonic acid gas was obtained, having a temperature of $66^{\circ}.425$. Five artesian wells, sunk at Heilbronn, on the Neckar, yield water of $54^{\circ}.5$.** The mean temperature of the places in Würtemberg falls between $47^{\circ}.75$ and $50^{\circ}.0$. In the Amalienbad Langenbrücken, in Baden, a strong sulphurous spring of $56^{\circ}.75$ was obtained by boring.†† According to my observations on ten artesian wells at Münster, in Westphalia, their temperatures seem to exceed the mean tem-

* Die artesischen Brunnen in und um Wien von Jacquin und Partsch. Wien, 1831.

† Kastner's Archiv. für Chemie und Météorologie, vol. iv. p. 48.

‡ Ibid. vol. ii. p. 228.

§ Ibid. vol. iv. p. 374.

|| Von Bruckmann ueber artesischen Brunnen. Heilbronn, 1833, p. 224 and 229.

¶ Correspondenzblatt des Königl. Würtemb. landwirthschaftl. Vereins, 1833, vol. ii. No. 2. p. 152-1.

** Von Bruckmann, p. 34.

†† Ibid. 248.

perature of the place by about $2^{\circ}.25$. Some springs bored for in the East Pyrenees also exceed the mean temperature of that country by several degrees; thus one at a depth of 80 feet had $60^{\circ}.35$, exactly the same as the running springs in the neighbourhood; a second, at a greater depth, shewed $62^{\circ}.825$.* Lastly, at Rüdersdorf, near Berlin, in the chalk formation, water of $74^{\circ}.3$ was obtained at a depth of 880 feet, 770 feet below the surface of the sea.†

This comparison of the temperatures of springs shews that thermal waters are to be found in all formations very abundantly. They are found in the youngest members of the secondary series, as well as in the oldest neptunian and in volcanic rocks. We find them below the level of the sea, a few hundred feet above it, and at heights of 2000 to 12,000 feet.‡ Warm

* Bulletin de la Société Geolog. de France, vol. iv. p. 214.

† Poggendorff's Annalen, vol. xxviii. p. 233.

‡ I only mention a few warm springs as examples: Ems lies 291 feet above the level of the sea, Wisbaden 323 feet, Aix-la-Chapelle 400 to 500 feet, Pfaffers 2128 feet, Gastein 3100 feet, Leuk 4400 feet, Brennersbad in Tyrol ($72^{\circ}.5$), 4500 feet; the warm springs of Dux ($56^{\circ}.75$ to $72^{\circ}.5$, discovered by Ennemoser), 5600 feet. In the Cordilleras rise the sulphurous springs of Juan ($89^{\circ}.6$) and Aqua Tibia ($96^{\circ}.8$), at a height of 12,313 feet above the sea. Boussingault remarks (Annales de Chimie et de Physique, vol. lii. p. 181), that at different points in the Cordilleras, there are appearances which speak in favour of the opinion that the heat of warm springs is caused by the superior temperature of the interior of the earth. Thus, it seems that the hot springs in the chain of Venezuela have a less elevated temperature the higher they are situated; for example, the hot spring at Las Trincheras, near Puerto Cabello, almost on the level of the sea, has $206^{\circ}.6$; the spring of Mariana, 1465 feet above the sea, only $147^{\circ}.2$; and the waters of Onoto at a height of 2161 feet, only $112^{\circ}.1$. In the trachytic districts, particularly in the vicinity of volcanos, this regularity in the decrease of the temperature of the springs is no longer observable; and it seems that in this case the local cause, which occasions the volcanic phenomena, has an extraordinary influence upon the temperature of these waters. Anglada (p. 54) shews, on the other hand, that the temperature of thermal springs does not always decrease with the increase of elevation at which they rise. But how could such be always expected, even if they were only indebted to the heat of the interior of the earth for their superior temperature? For, since their temperature depends upon the depth to which the meteoric waters sink through the clefts, it may easily happen that a spring rising at a greater elevation, but coming from a greater depth, should have a higher temperature than another rising at a lower level, but from a lesser depth.

springs are also found in all latitudes: in the polar regions, as in Iceland and in Greenland,* as well as in the temperate zone and under the equator. The heat which accompanies them cannot, therefore, be sought in any particular formation of rocks, nor in local chemical processes, but must be everywhere distributed throughout the interior of the earth. We must necessarily be brought to this conclusion, so soon as we succeed in proving that it cannot possibly result from any chemical processes.

CHAP. II.—*Can the elevated temperature of acidulous springs be a consequence of the absorption of carbonic acid gas?*

Leop. von Buch,† in the communication of his observations on the temperature of the springs in the *Canary Isles*, finds it very remarkable how small a proportion of carbonic acid gas is sufficient to influence the temperature of springs. “But however astonishing,” he says, “this circumstance may be, it is nevertheless not peculiar to these islands, but, on the contrary, of rather general occurrence. At least I have not as yet been able to discover any acidulous waters, whose temperature has not invariably exceeded that of the fresh water springs.”

The experiments of Henry,‡ by which he found that carbonic acid gas and water of equal temperature, acquired, by their mixture, an increase of temperature of only $0^{\circ}.45$ to $0^{\circ}.743$ were already unfavourable to this hypothesis. However, in order to ascertain what increase of temperature would actually result from the absorption of heated carbonic acid gas by water, I formed carbonic acid gas by heating carbonate of lime in a gun-barrel, and made it pass into a receiver filled with water. The quantity of water in the receiver was 174.5 volumes, and that of unabsorbed carbonic acid gas, which had collected over the water, 60 volumes. The temperature of the water at the beginning of the experiment was $44^{\circ}.375$, and after the absorption of the gas was $45^{\circ}.275$; total increase $0^{\circ}.9$.

A part of this increase must, however, be attributed to the heat of the room ($54^{\circ}.5$ to $56^{\circ}.75$) during the hour and a half that the experiment lasted, and to the strong charcoal fire neces-

* Gilbert's *Annalen der Physik*, vol. lxii. p. 174.

† Poggendorff's *Annal. der Physik*, vol. xii. p. 415.

‡ Philosophical Transactions for 1803, p. 1.

sary for the evolution of the gas, notwithstanding that the receiver was guarded from the radiated heat by a screen.

To ascertain the temperature of the gas at the moment of its leaving the gun-barrel, I introduced a very delicate thermometer immediately into the stream of gas at the moment of its escape; it rose, however, only to $88^{\circ}.25$, although the gun-barrel, at the end from which the gas issued, had a temperature of $144^{\circ}.5$. A repetition of this experiment gave the same result.*

If, then, we suppose that, at a certain depth in the earth, carbonic acid gas is generated in a similar manner, by the heating of carbonate of lime to a red heat, and that it is absorbed at a certain height above this subterranean laboratory by the waters of springs, the temperature of those springs could only be raised about $0^{\circ}.9$.

Leop. von Buch says farther, that the elevated temperature of acidulous springs is easy to be understood, if we consider for a moment how they make their appearance on the surface. They always owe their existence, namely, to the escape of carbonic acid, from hot mineral springs strongly impregnated with gas, which exist in clefts or in narrow valleys, at a considerable depth. The carbonic acid expelled by the hot water escapes, making a passage up through the cracks in the rocks, combines with the colder waters with which it meets, and comes to the surface in the shape of acidulous springs, bearing a temperature somewhat above the original temperature of the water.

In order to make a trial of this hypothesis by means of a few direct experiments, I evolved carbonic acid gas by boiling an acidulous water, which was very rich in carbonic acid, in a retort, and introduced a very delicate thermometer into the mouth of the retort, immediately in the stream of gas. The temperature of the mineral water before the experiment was $57^{\circ}.65$,

* The greater part of the heat which the carbonate of lime receives, seems to be applied in converting the carbonic acid into the gaseous state. It is singular that carbonic acid gas disengaged from chalk by means of concentrated sulphuric acid, acquires a much higher temperature than that which is liberated by heat. The temperature of the gas disengaged by sulphuric acid rose to $133^{\circ}.25$, and would, doubtless, have risen still higher, had not the mass, in consequence of the too violent escape of the gas, come into contact with the thermometer. The temperature of the mass itself was much above 212° .

that of the air at the mouth of the retort $64^{\circ}.175$. The thermometer did not rise to $65^{\circ}.75$ until some drops of water had distilled over. At this point it remained for several minutes, whilst the mineral water continued to boil, and it was not until aqueous vapours were visible that it rose by degrees as high as 212° .

It is, therefore, quite evident that the carbonic acid gas had a very small share in the raising of the thermometer, but rather that the aqueous vapours produced this effect.

I repeated this experiment, and luted a receiver filled with distilled water air-tight into the neck of the retort. The volume of the mineral water in the retort was to that of the distilled water in the receiver as 1 to 0.77. As the mineral water was over-saturated with carbonic acid, the water in the receiver could still, after subtracting the quantity of carbonic acid left in the mineral water, absorb nearly sufficient to saturate itself. The acidulous water was heated by degrees to $187^{\circ}.25$,* and kept for a long time at that temperature. The total increase of temperature, however, only amounted to $0^{\circ}.675$; which is just the same as was observed by Henry.

I again varied the foregoing experiment by causing a stream of carbonic acid gas, which I evolved from an acidulous water by boiling, to pass through a column of water 18 inches high. The volume of the column of water was equal to 1, that of the water from which the gas was evolved equal to 3.37, that of the space in the retort unoccupied by the mineral water equal to 6.63, and the volume of the gas contained in the water may be taken at least as equal to 4. As the boiling was kept up so long as gas continued to rise, about 10.63 volumes of carbonic acid gas and atmospheric air must have passed through the column of water. The temperature of the air during the experiment was $60^{\circ}.125$, that of the column of water at the commencement $54^{\circ}.5$; and, until the water in the retort began to boil, the highest temperature it acquired was $61^{\circ}.8$. But afterwards, when great quantities of aqueous vapour accompanied the carbonic acid gas, it rose by degrees to $180^{\circ}.5$; and it is evident that these vapours must have also had some share in the increase of $7^{\circ}.2$ observed before the mineral water began to boil.

* The cement with which the thermometer was luted into the tubulus of the retort would not allow of a stronger heat.

From all these experiments it follows, that the heat of acidulous springs cannot be ascribed to the carbonic acid gas itself, but principally to the aqueous vapours which accompany it, for, as Von Buch imagines the production of acidulous springs, the vapours of water must also assist in raising their temperature. Besides, this hypothesis presupposes the existence of an elevated temperature below the origin of these springs; so that we need only suppose them to descend into the vicinity of those hot springs, and they will acquire an elevation of temperature, independently of the inconsiderable increase caused by the absorption of the carbonic acid gas.

If the rising of springs follows the laws of hydrostatics, it is easy to conceive how carbonic acid gas and aqueous vapours should find their way into the channels through which they flow. I have made several experiments on this subject.* I connected two glass-tubes, each of four feet long, by a brass pipe, in such a manner as to form an inverted syphon. At the side of the brass tube, another tube was fixed at right angles to it, having a cock in it, the opening of which was very narrow; to this was luted a small tubulated retort. When the cock was shut the apparatus formed an uninterrupted syphon; and even when it was open, the water continued to flow out of the shorter tube, so long as it continued to be poured into the longer one; for the air in the retort was only compressed, without its being able, on account of the smallness of the aperture, to escape through the cock, and let in the water in its place. When carbonic acid gas was generated in the retort, and the cock opened, the gas rose through the water in the shorter tube, in separate bubbles, and escaped from the water collected in a small basin fixed on the top of that tube. During the evolution of the gas in this apparatus, which is a true representation of the course of a mineral spring, the water flowed without interruption out of the basin. Now, as, under these circumstances, where each bubble of gas entirely filled up the channel, and, at the moment of its escape, caused an interruption in the course of the water, there was no perceptible interruption in the flowing off, still less can such an interruption take place in nature, where the bubbles must certainly very seldom fill up the channels through which they pass.

* Poggendorff's *Annal.* vol. xxxii. p. 261.

If, lastly, we suppose the carbonic acid gas to be forced into the course of the water under a great hydrostatic pressure, it must be immediately absorbed, and must, therefore, have still less power to disturb, and will only disengage itself again by degrees in higher regions, as the hydrostatic pressure gradually decreases.

Thus we see that the possibility of the creation of acidulous springs according to Von Buch's hypothesis, is by no means to be denied. Whether all such springs originate in this manner, may, however, be a matter of doubt. By far the greater part only exceed the mean temperature of the neighbouring fresh-water springs by one or a few degrees. The origin of these cannot, therefore, be very deep; and yet the aqueous vapours, which must necessarily join them in their course, in order to effect an increase in their temperature, since that caused by carbonic acid gas alone is scarcely perceptible, must come from a great depth. In places where volcanic action still exists, the appearance of fumaroles (evolutions of aqueous vapour) on the surface of the earth is very frequent; as, for instance, Italy (viz. in Tuscany), in the Lipari Islands, and so on. But is any thing similar to the fumaroles to be met with in countries of extinct volcanic action, in which most of the acidulous waters are found, such as the neighbourhood of the Laacher See, the volcanic Eifel, Bohemia, &c.?

It might be objected, in order to ascribe the heat of acidulous springs to carbonic acid *alone*, that the results of my experiments, made under the ordinary atmospheric pressure, can be no criterion of the increase of temperature acquired by water in the interior of the earth, where a considerable hydrostatic pressure augments the absorption of the carbonic acid gas in a high degree. It is true the increase of temperature of the water will be greater the more carbonic acid gas it absorbs. But when water, having absorbed five times its volume of carbonic acid gas in the interior of the earth, comes to the surface, it can at the utmost retain but $1\frac{2}{3}$ its volume of free and half carbonic gas; at least, that is the maximum I have found by many analyses of the richest carbonated springs. The heat which the water has acquired by the absorption of the carbonic acid, independently of the heat of the acid itself, must, therefore, re-escape

as the spring rises to the surface, when the gas disengages itself again, and, as is so often the case with rich carbonated springs, issues forth in uninterrupted streams.

The evolution of carbonic acid gas from acidulous springs, which is in some cases so enormous, might perhaps lead us to conjecture, that it for the most part proceeds from streams of gas, which come up from the interior without having yet been absorbed by water. But I have found, by measuring the quantity of carbonic acid gas and water yielded in a certain time by one of the richest carbonated springs, that the gas evolved, and that which was absorbed by the water, together, only made up 5.3 times the volume of water.*

Supposing, then, that this gas came in contact with the water at a depth of only 170 feet, the hydrostatic pressure which would be there exerted, would be sufficient to cause the absorption of 5.3 times the volume of the water. But this spring, bearing a temperature of 9° above the mean temperature of the place, certainly rises from a much greater depth. The supposition, therefore, that a great quantity of heated carbonic acid gas could assist in the elevation of the temperature of a spring, by passing through its channels, is proved to be unfounded.

It appears from observations made on the Mofettas, which usually succeed great eruptions of Vesuvius, that carbonic acid gas evolved, according to Von Buch's hypothesis, cannot possibly have a temperature equal to that of carbonic acid gas disengaged from chalk submitted to a red-heat in a gun barrel. Thus Monticelli and Covelli† found, that cavities filled with the mofettas, were only 3°.85 warmer than those in which no mofettas existed. If, then, streams of carbonic acid gas, issuing forth so near their volcanic origin as these do, shew so low a degree of heat, it cannot be expected that such as rise in the neighbourhood of extinct volcanic action should be warmer. Nor have I observed a superior temperature in any which I have examined of the numerous exhalations of carbonic acid gas which occur in the

* Poggend. Ann. vol. xxxii. p. 251.

† Storia de Fenomeni del Vesuvio, avvenuti negli anni 1821, 1822. e parte del 1823, con osservazioni e sperimenti di T. Monticelli e N. Covelli. Napoli, 1823. Translated into German by Nöggerath and Pauls. Elberfeld, 1824, p. 193.

vicinity of the Laacher See and in the Eifel. I do not, however, consider this as a sufficient proof, as, in my opinion, all these exhalations proceed from mineral springs situated below them.*

If we assume that, from whatsoever cause, water in the interior of the earth is heated to 212° , and that carbonic acid gas of a temperature much above the boiling point be forced at the same time through it; that water would not only not become more heated, but, on the contrary, would suffer a diminution of its temperature, on account of the evaporation. This may, perhaps, be one of the causes that so few of the known hot springs reach the boiling point.

I support this assertion upon several experiments which I made for that purpose. Thus, on driving air heated to the melting point of tin in such considerable quantities as a large double action bellows was capable of giving, for a whole hour, through about 12 ounces of water $60^{\circ}.125$, it only caused the temperature of the water to rise to $119^{\circ}.75$. Indeed, when the water was surrounded by other water kept continually boiling, the passing of the heated air through it always caused a depression, greater or less, of its temperature; in one case from 194° to 158° . The boiling of the surrounding water decreased in violence perceptibly when the heated air was let in to the water, and, on the other hand, increased, when the streams of hot air was interrupted.

To all the objections already taken to the hypothesis that carbonic acid gas is the cause of the warming of acidulous springs, it may be added, that their temperature does not always exceed that of the fresh-water springs. In April 1833 I found the temperature of the acidulous waters of Meinberg, and of the carbonic acid which is disengaged from them in great quantities and with great violence, to be only $41^{\circ}.45$. Among the observations communicated in Chap. VI. on the temperature of these springs at different seasons, we find that their yearly mean differs but little from that of the neighbouring fresh-water springs. The carbonic acid cannot, therefore, increase their temperature at all, although they contain 0,9 and 1,31 times their volume of

* Poggend. Ann. vol. xxxii. p. 248.

that gas.* Every thing speaks in favour of the supposition, that these acidulous waters are formed near the surface, where streams of water and carbonic acid gas come in contact with each other.

Lastly, if we take into consideration that by far the greater part of the fresh-water springs of artesian wells, which seldom contain a larger proportion of carbonic acid than those of common wells, have, however, a temperature exceeding the mean temperature of the place in many cases by several degrees, we find ourselves obliged to seek another cause for the elevated temperature of such springs. I only bring forward, as an example, the above-mentioned warm-springs of Paderborn, whose temperature is as high as $61^{\circ}.25$, and which, however, only contain one-tenth of their volume of carbonic acid gas, whilst the neighbouring springs of Schmechten, Hester, Driburg, and Pyrmont, so rich in carbonic acid, only give $48^{\circ}.2$ to $54^{\circ}.5$. In like manner, the temperature of the salt-springs of Westphalia falls between $52^{\circ}.25$, and $63^{\circ}.5$, although they are also very poor in carbonic acid.

CHAP. III.—*Can the Heat of Thermal Springs be the result of chemical processes or of local circumstances? and can local circumstances cause any modifications in the Temperature of thermal springs?*

With regard to the former of these questions, two cases may be imagined: either that the heat of the springs is the result of chemical processes acting in the mineral waters themselves, during their formation, and by which their mineral contents are produced, or, that chemical processes take place in the vicinity of the course of the mineral springs, by which their channels become heated from without.

Respecting the first case, it is quite evident, that such a chemical process cannot be the solution of salts already in existence; for then, on the contrary (with one exception only, namely, when anhydrous salts, which require much water of crystallization, come in contact with water), cold would be the result. But since salt-water springs are also thermal, and, in-

* The salt-spring at Schieder, on the other hand, though only three miles from Meinberg, and containing only 0.37 volumes of carbonic acid gas, is, nevertheless, warmer than those carbonated springs.

deed, warmer the more salt they contain (which is considered a general rule by salt-workers), and as it may be considered quite certain that they derive their saltiness from deposits of rock-salt, a contradiction here presents itself, and we must consequently conclude, at least for salt-water springs, that they are not indebted to chemical processes of the first kind for their superior temperature.

The greatest evolution of heat would take place, if the elements of the salts, contained in the mineral springs, entered into combination at the moment of the creation of those springs. In order to have an idea of the degree of heat which would be produced in this case, I made the following experiments :—

The Heilbronn, a mineral spring in a small valley of the Brohl, four miles distant from the lake of Laach, is, next to Bilin in Bohemia, the richest in carbonate of soda known to me. It contains 0,0053 of fixed substances. Supposing that this spring were formed from anhydrous carbonate of soda, by the addition of concentrated sulphuric acid, muriatic acid, and water, then, according to my analysis, 77,4 parts anhydrous carbonate of soda, 5 parts concentrated sulphuric acid, 92 of smoking muriatic acid, and 22,687 parts of water would be required to compose a water, containing the same proportions of carbonate and sulphate of soda, and of chloride of sodium, as that spring. In accordance with this, therefore, I put 77,4 grains of calcined carbonate of soda to 22,687 grains of water. The temperature of the water was,—

Before the experiment,		42°.8
After,		43°.7
Increase of temperature,		0°.9

To this solution of soda I added a mixture of 5 grains concentrated sulphuric acid, and 92 grains smoking muriatic acid.

The temperature of the two liquids was,—

Before their mixture,		50°.00
After,		50°.45
Increase of temperature,		0°.45

Now, although such a chemical process as this, which is very improbable to take place in the interior of the earth, is the most favourable for the production of heat ; still, it only caused an

increase of temperature of $1^{\circ}.35$. Since, then, atmospheric water, under similar circumstances, having the temperature of the place, would, by dissolving so much of the above-mentioned substances as to form one of the richest mineral springs of Germany, only acquire a temperature of $1^{\circ}.35$ higher than that of the neighbouring fresh-water springs, the increase of temperature caused by this process in such mineral springs as frequently only contain one-half to one-sixth as much of soluble ingredients as the Heilbronn, could not be perceptible.

If we even admit the most favourable case for an increase of temperature, but in *rerum naturâ* the most improbable case of all, viz., that sodium should come in contact with water containing the necessary quantities of sulphuric, muriatic, and carbonic acid to form such a mineral water as the Heilbronn; even then, only an inconsiderable elevation of temperature would take place, as the following experiments verify:—

Fifteen grains of sodium were put into a goblet, and a small glass funnel placed over it; upon this were poured 1000 grains of water in which so much sulphuric and muriatic acid were mixed as would form such a mineral water as that of the Heilbronn. A violent explosion, accompanied with a shower of fire, was the consequence, and the glass broke.

The heat of the water was,—

Before the experiment, ...	52°.925
After, ...	55°.850
Increase of temperature,	2°.925

In a repetition of the experiment in a metallic vessel, the increase of temperature was 4.275.

The increase of temperature, caused by the oxidation of the alkaline metals by water, is, therefore, far from sufficient to account, as Von Buch has attempted,* for the existence of hot springs. Neither is there more probability in Boussingault's hypothesis,† that the hot-springs which rise in the granite of the Littoral Corderillas may be the result of the action of water upon sulphuret of silicium, by which warm water, containing

* Abhandlungen der K. Akad. der Wissenschaften in Berlin aus den Jahren, 1818, 1819, p. 65.

† Annal. de Chimie et de Phys. Février, 1833, p. 189.

silica and sulphureted hydrogen, would be produced; for those springs contain very little of these substances.

The formation of mineral springs by the decomposition of water by the alkaline metals, is, indeed, contradicted by the circumstance that, in that case, streams of hydrogen gas must issue with the water, which has not as yet been observed in any springs.

There is also another argument against the possibility of any chemical process being the cause of the heat of thermal springs, which is in some cases so very considerable, namely, that it is by no means a general rule that those springs which contain the greatest quantity of fixed substances, are the hottest. Thus, for example, within the space of about one mile, in the vicinity of the Laacher See, are found the following mineral springs, whose quantities of fixed constituents and temperatures confirm my assertion, at least for that neighbourhood.

	Fixed Constituents.	Temperatures.
Heilbronn, ...	0,0053	52°.925
Tönnstein, ...	0,0025	54 .950
Fehlenbor, ...	0,0019	57 .650
Burgbrohl, I. . . .	0,0013	58 .100
Burgbrohl, II. . . .	0,0008	53 .600

Still less is it the case with the alpine springs Gastein and Pfäfers, which contain less fixed and gaseous substances than common spring water, and are, consequently, little else than pure warm water; not to mention the pure water springs and artesian wells, which are frequently warmer than neighbouring mineral springs containing fixed substances in great abundance.

If there existed mineral springs consisting of a concentrated solution of sulphate of iron, a superior temperature would be more conceivable; although even then the elevation could hardly be perceptible, as the slow decomposition of the magnetic pyrites in the copperas manufactories proves.

Against the second case, namely, that chemical processes take place in the vicinity of the course of mineral waters, by which the sides of the hollows and clefts through which they flow become heated from without, several objections may be made. In the first place, traces of such chemical processes would surely be visible, if the seat of their action were in communication, by means of the clefts, with the surface. But in that case, the

meteoric waters would also have free access to that place, and would either increase, diminish, or entirely extinguish the chemical action; or would somewhere reappear charged with substances which had taken a part in the process. Of this, however, experience furnishes no examples. Secondly, if we suppose the process to be an oxidation, the free admission of the oxygen of the air would be necessary. But then the atmospheric waters would also have access, since such a process cannot be conceived without a communication with the atmosphere, and nitrogen gas would be evolved in much greater quantities than are found here and there sparingly emitted from some few mineral springs.

Thirdly, if this oxidation be supposed to take place at the expense of water, hydrogen gas must be evolved, which is also contrary to experience. Such an explanation of the heat of mineral springs necessarily presupposes a structure in the interior of the earth of quite a peculiar nature, viz., one cavity enclosed within another, and one to which nothing analogous has been found in the working of mines; the theory must, therefore, be considered as untenable.

It must, however, not remain unmentioned, that subterraneous fire may, in solitary instances, give rise to warm springs. Examples of this have occurred in the Planitzer Adit, near Zwickau, and at Holdenstaedt near Eisleben in Thuringia.*

Lastly, it must also be taken into consideration, that formerly, when only the few commonly called hot-springs, such as Carlsbad, Aachen, &c. engaged the attention of philosophers, the explanation of this phenomenon could only be sought in local causes. Becher's hypotheses with respect to Carlsbad, that water containing common salt flows over a depot of burning iron-pyrites, or Klaproth's supposition that the water is heated by a considerable bed of coal, set on fire by iron-pyrites, were, therefore, for the moment considered satisfactory. Independently of the well-grounded objections of Von Buch and Berzelius to these hypothesis, there would still remain much for us to account for, even if we had very satisfactory explanations of those properly called hot-springs. For as the rising of thermal

* Kühn Handbuch der Geognosie, vol. i. 279.

springs is a phenomenon of very general occurrence, which may be traced through all formations, from the very youngest of the stratified to the very oldest rocks, the chemical processes which cause the heat of these waters must be equally universal. Or is it, perhaps, less difficult to account for the heat of a spring whose temperature only exceeds the mean temperature of the place by a few degrees, than to find an explanation for the creation of those commonly called hot springs?

Anglada* adds another argument of no small weight against the explanation of the heat of thermal springs by any chemical process, namely, that it would be difficult to conceive how such a process should continue in action for so long a time, and with such uniformity as would be necessary to explain the uninterrupted course of the springs, their uniform productiveness, and their unvarying temperature and composition.

Since, then, we are obliged to admit that the conditions necessary for the production of warm springs must exist in all parts of the earth, we find ourselves imperceptibly led to the hypothesis of a superior temperature in the interior of the earth.

Laplace already endeavoured to account for the heat of thermal springs, and their uniformity within the memory of man, by this internal heat of the earth.† Subsequently, it has been shewn by Arago,‡ that the temperature of artesian wells is higher the deeper they spring; and he has brought this forward as a proof, that the temperature of the strata of the earth increases constantly with the depth. Anglada, || who is also led to this hypothesis, thinks, that if the heat of mineral waters were only caused by the increase of temperature towards the centre of the earth, it would be contradicted by our not meeting every

* *Mémoire pour servir à l'Histoire, &c.* vol. i. p. 15.

† *Annal. de Chim. et de Phys.* vol. xiii. p. 415.—This philosopher says, "Si l'on conçoit, que les eaux pluviales, en pénétrant dans l'intérieur d'un plateau élevé, rencontrent, dans leur mouvement, une cavité de trois mille mètres de profondeur, elles la rempliront d'abord; ensuite, acquérant à cette profondeur, une chaleur de 100° au moins, et devenues, par là, plus légères, elles s'élèveront, et seront remplacées par les eaux supérieures, en sorte, qu'il s'établira deux courans d'eau, l'un montant, l'autre descendant, perpétuellement entretenus par la chaleur intérieure de la terre. Ces eaux en sortant de la partie inférieure du plateau auront évidemment une chaleur bien supérieure à celle de l'air au point de leur sortie."

‡ *Annal. de Chim. et de Phys.* vol. xxix. p. 317.

|| P. 17.

where with the effect of a cause supposed every where to exist ; as thermal springs are in some places very abundant, whilst in others they are totally wanting.

It is evident that Anglada only took those commonly called hot springs into consideration. But since thermal springs are so universally distributed over the earth, that which he opposes to our hypothesis, argues, on the contrary, in its favour.

Perhaps, he says, the phenomenon of thermal springs may be best accounted for by the action of electromoters (*electra-moteurs*), existing in the interior of the earth. Many German philosophers are also known to have inclined formerly to this hypothesis ; but the greater part, at least those whose object is not merely speculation but research, have now abandoned it.* It may, however, perhaps, not be quite superfluous briefly to examine the grounds which Anglada, a philosopher to whom we are indebted for so many and such profound researches on mineral waters, brings forward in support of such an hypothesis.

According to him, there are many appearances on the surface of the earth which indicate the existence of electromoters. As, for instance, the Heideberg in the Fichtel-Gebirge, which Von Humboldt discovered in the year 1796 to be polar magnetic.† But by more recent inquiries, I have endeavoured to shew that that polarity is only a consequence of the magnetic pyrites contained in the rock.‡ If, as Anglada supposes, there exists an electromotric power corresponding with the magnetic polarity, and if the former is the cause of the heat of thermal waters, then springs rising in the vicinity of lodes or beds of magnetic iron-ore (oxydulated iron) must always have an elevated temperature. But this is by no means the case ; for example, in Sweden, Siegen, and the Duchy of Westphalia, where considerable lodes and beds of that mineral are found.

Anglada is of opinion, that although the constant running and the uniform temperature of warm springs agree very well with

* See Bischof, *die Vulkanischen Mineralquellen*, &c. p. 321 and following. Perhaps I have the merit of having assisted in the downfall of this singular hypothesis.

† See Gren's *Neues Journ.* vol. iv. part 1, p. 136 ; and Von Humboldt's subsequent remarks in the *Annal. de Chim. et de Phys.* vol. xxv. p. 327.

‡ Goldfuss and Bischof *Physikal-Statistische Beschreibung des Fichtelgebirges*, 1817, part 1. p. 193. and following.

the opinion that they owe their heat to that of the interior of the earth, it would still be impossible to account by that means for the accidental variations which the temperatures of springs suffer. And he maintains that his hypothesis is satisfactory in this respect, the more particularly as such alterations generally take place during earthquakes, and therefore prove themselves dependent upon those great electrical phenomena (?).

These objections are easily set aside. If alterations of the temperature and chemical composition of springs generally happen during earthquakes, they may be caused by the opening or closing of fissures, by which the waters come into contact with other substances, or by their coming from a greater depth, bring with them the loose contents of the clefts in the rocks. If the fissures open further, the atmospheric waters will sink deeper, and become more heated; if they close, the contrary will take place. According to Dr Ambrozzi,* the warm waters of Tep-litz flow more copiously since the earthquake which destroyed Lisbon on the 1st November 1755, than before; during the earthquake they become muddy, flowed one hour and a half of a dark yellow colour, and towards mid-day entirely disappeared during six or seven minutes, then suddenly gushed forth again, and for half an hour continued to emit a thick yellowish-red water, in such quantities that the baths were overflowed; whereas the medicinal springs of the village of Söchnau, of Carlsbad, and all others, with the exception of some in Morocco, remained unaltered.

An alteration of temperature and chemical composition has often been observed in springs which rise in the vicinity of active volcanos. Thus, according to Dolomieu,† the spring of Macaluba, which in the year 1781 emitted atmospheric air and carbonic acid gas, only yielded a kind of inflammable gas in the year 1785. Other examples of alterations taking place in the temperature of springs situated near active volcanos will be given afterwards. On the other hand, springs rising in the neighbourhood of extinct volcanos shew a great uniformity

* *Physikalisch-Chemische Untersuchung der Warmen Mineralquellen zu und bey Teplitz. Leipzig. 1797.*

† *Sur les Isles Ponces, p. 368.*

of temperature and chemical composition during long periods of time.

The same effects which earthquakes are capable of causing in springs, will also be produced by active volcanos, for volcanic action is always accompanied by earthquakes. Besides, by the rising of the melting lava, the upper strata of the earth become heated, and thus it may happen that springs rising in a volcanic soil, although from an inconsiderable depth, may, as Anglada himself remarks, be warmer than others which do not rise in volcanic districts.

All such variations may, therefore, take place without injury to the hypothesis, that the superior temperature of the interior of the earth progressively increasing with the depth, is the principal cause of the heat of thermal springs. It is, therefore, unnecessary to seek refuge with Anglada in such an improbable subterranean electrical process.

It still remains to be ascertained whether a gradual alteration of the temperature of springs, in places where there are neither traces of former nor of present volcanic action, and where earthquakes are not frequently felt, can be conceived possible. With respect to the phenomenon itself, it is difficult to determine whether it exists or not; for all depends upon the thermometers, which, so constructed as to serve for a comparison of observations on the temperature of springs, have only been in existence for about one century. But it is well known that even until a much later date, exactly corresponding thermometers were considered great rarities; and it is not long since attention has been drawn to several circumstances, upon which the accuracy of these instruments depends. It is true that considerable differences of temperature may be observed in springs even with inaccurate thermometers; but if they proceed by degrees, and are not perceptible until a long period has elapsed, the most perfect apparatus is necessary for their detection. According to the observations of Carrere in 1754, and those of Anglada in 1818 and 1819,* the temperature of ten thermal springs in the East Pyrenees, has decreased $1^{\circ}.125$ to $60^{\circ}.75$ during that period, and the decrease was found to be greater the higher the original temperature of the springs.

* Anglada, p. 63.

Besides the accidental causes which may lower the temperature of thermal springs, such, for instance, as meeting with colder waters, there seems to be another very important one, viz., that mineral springs frequently fill up their own course by a partial precipitation of their constituents. If such a precipitation takes place in the lowest part of the spring's course, and advances gradually higher and higher, the consequence naturally must be, that the meteoric waters, no longer able to sink down to so great a depth, by degrees becomes less and less heated. The deposit from the Carlsbad springs may here be cited as an example; although in this case the deposit is only observed on the surface, and the cause of its precipitation above cannot so easily exist below. The enormous deposits of travertin are well known. In that occasioned by the hot springs of San Filippo, fissures of 30 feet deep and 150 to 200 feet long are observed. A particularly important and direct proof is the calcareous deposit in the Roman aqueduct between Cologne and Treves. It has been deposited since the time of the Romans, from several fresh-water springs, and is seven or eight inches thick in some places, so that it has been used for columns of churches.

I have elsewhere* called attention to the veins of brown ironstone in the trass of the Brohlthal, which may often be traced to a great distance on the bare walls of ravines and quarries in that rock, and which certainly owe their existence to no other cause, than that ferruginous waters, of which there are still a great many in existence in that district, formerly flowed in those cracks, and by degrees deposited hydrate of iron, thereby filling up their own course. Such fillings up with hydrate of iron are also found in the greywacke, in basalt, in trachyte,† and other rocks. Inferring from the deposits of sphaerosiderite from mineral springs actually observed, I have endeavoured to shew that veins of carbonate of iron and brown ironstone may also often be the sediment of mineral springs.

I have already proved‡ that when springs contain any sul-

* Schweigger-Seidels n. Jahrb. der Chemie und Phys. vol. viii. p. 431.

† Vues et coupes des principaux formations géologiques du Dép. du Puy-de-Dôme, &c., par Lecoq et Bouillet, Clermont Ferrand, 1830, 8me. livraison, p. 223.

‡ A. O. vol. iv. p. 386. See also Longchamp in the Annals. de Chim. et de Phys. vol. xxxii. p. 294.

phates, together with iron and an organic substance, iron-pyrites is very easily formed, and in this manner they may fill up their subterranean channel. This may also happen when two different mineral springs meet in one cleft, one of which contains carbonate of protoxide of iron, and the other a sulphate and an organic substance. And nothing is more common in mineral springs than these substances. In general, many cases may be imagined, in which the confluence of mineral springs composed of different ingredients, might occasion such sediments as would by degrees fill up their passage. For example, if springs containing earthy salts should meet with others containing alkaline carbonates; or if waters rich in silica * should meet with organic substances, whether in solution, or in the solid state by which, as I have shewn, siliceous concretions would be formed.

In the above-mentioned sulphurous springs of the East Pyrenees, iron-pyrites and earthy carbonates might easily be formed at the expense of their sulphuret of sodium and their alkaline carbonates, by their meeting with other springs containing salts of iron and earths, and thus the channels of these springs becoming gradually filled from the bottom, the waters would by degrees be enabled to sink less and less deep into the earth. †

Lastly, an obstruction in the course of the springs may be occasioned partly by chemical and partly by mechanical means. I have pointed out ‡ several appearances which make it seem very probable, that ferruginous waters act as a cement upon loose stony materials, namely, upon sand, and may thus give rise to the formation of stony concretions. There is no doubt that waters containing much silica occasion siliceous concretions, such as are found very characteristic in the sandstone belonging to the lignite (braunkohl) formation, and also in other positions. And surely concretions of this kind may also easily be formed in the

* In the great Geyser, the deposits of silica have accumulated in a crack to the thickness of 12 feet.

† Supposing the increase of temperature in plains and in enclosed valleys to amount to $2\frac{1}{2}^{\circ}$ in 115 feet, it is easy to perceive, that if the lower parts of a spring's course be very narrow, and the spring be rich in any substance easy to be precipitated from it, no great length of time will be required to effect a perceptible decrease of temperature.

‡ Schweigger-Seidels n. Jahrb. der Chemie & Phys. vol. viii. p. 437.

channels of springs from sand and stones mechanically torn off or borne along by the stream. Since hot springs and aqueous vapour are able to act very powerfully even upon hard rocks, such, for instance as marble, and thus to acquire quite a muddy consistence, as I have observed in the Kaiserbad at Aix-la-Chapelle, and in the baths at Burtscheid ; the channels of springs may also in this manner become stopped up, especially if the spring have a cementing property.

Anglada supposes that the loss of heat, occasioned in the inner strata of the earth, by warm springs, is not restored by the power of conducting heat of the materials composing the interior of the earth ; and that the strata must consequently suffer a gradual diminution of temperature throughout the sphere of action of those cooling agents.

A gradual diminution of the internal temperature of the earth, caused by the loss of the heat carried off by thermal springs, cannot be doubted, so long as that loss is not repaired by any means. But whether that diminution has become perceptible within historical times or not, is another question.

The various degrees of temperature with which atmospheric waters sink into the earth at different seasons of the year, are already equalized in the uppermost strata of the earth's crust ; for springs which rise from a moderate depth shew but a trifling variation of temperature throughout the year, and that of thermal waters is, in general, quite constant. The heat carried by the pluvial waters into the earth, is, therefore, lost, in the almost inexhaustible provision of the earth's internal heat. The waters having soaked through the earth's exterior crust reach the strata, where the increase of temperature begins, with a constant or nearly constant temperature. At this limit the difference between the temperature of the channels and that of the waters can, therefore, only be infinitely small ; and as the waters, by sinking through strata always increasing in temperature, become gradually warmer, it may be assumed that the difference is infinitely small in every point of their course. That difference can only be perceptible when the waters do not filter through the strata finely divided, but flow in considerable streams. But the smaller the difference between the temperature of the waters and that of the channels through which they

flow, the less considerable will be the loss occasioned by the waters in the temperature of the strata. But, even supposing that by degrees a considerable local depression of temperature should take place in the channels of the springs, or, in other words * that in them the increase of temperature towards the centre of the earth should have become less rapid ; then the heat in their environs would be conveyed to them the more quickly, because the rapidity with which heat is transmitted from one body to another, increases in proportion to the difference between the temperatures of the two bodies. In no case, then, is it conceivable that a local cooling of the earth should be continually in progress, as Anglada is inclined to assume ; so that a gradual diminution of the heat of thermal springs can only be imagined in the case of a general cooling of the interior of the earth. But since the existence of thermometers, and since observations have been made on the temperature of springs, this general cooling has certainly not taken place in a perceptible degree. An actual diminution in the temperature of thermal springs, if no longer doubted, can therefore only proceed from the causes above enumerated.

CHAP. IV.—*Can Springs convey Heat from the Interior of the Earth to the Surface ?*

The universal occurrence of warm springs is alone sufficient to answer this question. But, independently of that, the possibility of springs pursuing a very long subterranean course, wherever their temperature may have been obtained, without suffering any considerable change, may also be indirectly shewn.

The coldest springs of the temperate zones rise in the vicinity of the glaciers, and on the limits of perpetual snow. Professor Ennemoser, at my request, determined the temperature of thirteen fresh-water springs near the glaciers, and on the limits of the snowy regions of the Tyrolese Alps, in the summer of 1833, and found them to vary from $36^{\circ}.50$ to $43^{\circ}.2$.

On the 28th August 1835, I found the temperature of four fresh-water springs, at the foot of the Gandecke, or Morene, of the upper glacier near Grindelwald, in Switzerland, 3684 feet above the level of the sea, to fall between $37^{\circ}.40$ and $38^{\circ}.075$; and, on the 3d of September, I found the tempera-

ture of fifty-one fresh-water springs on the Spital-Matte, between Kanderstäg and the Gemmi, 5887 feet above the sea, from $37^{\circ}.85$ to $40^{\circ}.10$.

- * According to former observations of Wahlenberg and Von Buch, * the springs on St Gothard, 8587 feet above the sea, have a temperature of $37^{\circ}.4$; and, according to Stampfer and Thurwieser †, one of the last springs, surrounded with vegetation, on the way to the Grossglockner, 6660 feet above the sea, in the vicinity of the glaciers has a temperature of $38^{\circ}.075$. Thus we find the lowest temperature till now observed, near the limits of perpetual snow, to be in summer $36^{\circ}.5$.

There is no doubt that many springs sink down from the snowy regions, through fissures in the rocks, and do not return to the surface until they have reached much lower levels; and since they are capable of maintaining their low temperature notwithstanding the higher temperature of the strata through which they have passed, it is evident that springs must be met with far below the limits of perpetual snow, bearing a temperature nearly the same as that of the springs rising near those limits.

In the Etschthal, above Partschins, near Meran, about 3000 feet above the sea, on the steep southern declivity of the mountain, Ennemoser found a very considerable spring rising in three places (the Oberhauser springs) to have a temperature of 41° . According to the observations of an apothecary in Meran, this temperature is constant throughout the year. The springs in the Etschthal itself, 1000 to 1200 feet above the sea, he found to have 50° to $54\frac{1}{2}^{\circ}$. It certainly cannot be supposed that, 1800 to 2000 feet above a country where figs and other southern fruits ripen, the temperature of the soil should be only 41° , nor that such a considerable difference of temperature could be attributed to so small a difference of elevation; but it seems rather that the spring near Meran derives its low temperature from its having descended from the neighbouring mountains. ‡ This is the more probable, as other springs in the neighbourhood of this one, and at an equal elevation, have $45^{\circ}.5$ to $47^{\circ}.75$.

* D'Aubuisson, *Traité de Géognosie*, vol. i. p. 427.

† *Jahrbücher des K. K. Polytechnischen Instituts in Wien*, vol. vii. p. 2.

‡ See Kupffer in *Poggendorff's Annalen*, vol. xv. p. 165.

Now, supposing that this spring originally had the temperature of springs on the limits of perpetual snow, it would, after a subterraneous course of 5200 feet, only have suffered an increase of temperature of about $3^{\circ}.15$.

In Passeyr, 5000 to 6000 feet above the sea, the fresh-water springs, according to Ennemoser's various observations, have a temperature of 41° to $43\frac{1}{4}^{\circ}$. However he found great variations here also. For instance, near Hittermühle, at an elevation of 5000 feet, rises a copious spring of $40^{\circ}.1$, whilst others 600 to 800 feet higher gave $42^{\circ}.125$ to $45^{\circ}.5$. At Hitte, behind Platte, there is a celebrated spring at an elevation of 4000 feet, which shews 41° , and the Goldbrunnen only $38^{\circ}.75$, whilst other neighbouring springs shew $43\frac{1}{4}^{\circ}$ to $47\frac{5}{4}^{\circ}$. On mountains of 7000 and 8000 feet, the springs have a temperature of $38\frac{5}{4}^{\circ}$ to 41° , with but few exceptions.

In several places in Switzerland I found springs, the temperatures of which were also much lower than might have been expected from the surrounding vegetation. Thus the temperature of four springs at the foot of the Great Eiger, near Grindelwald, which rises almost 9000 feet perpendicularly, was only $43\frac{5}{4}^{\circ}$.

Von Buch* found a spring near Neufchatel, in the Creux-du-vent, 2073 feet above the Lake of Neufchatel, and 3337 feet above the level of the sea, the temperature of which was $40^{\circ}.437$, whilst others nearly on the level of the lake, observed in different seasons and under different circumstances, gave 50° to $50^{\circ}.45$. He also found† that the temperature of the springs on Teneriffe shewed no great variations up to 4000 feet above sea, and that, in like manner, the temperature of the springs on the northern declivity of the Gran Canaria is $62^{\circ}.375$, up to 2000 feet above the sea. This can certainly not be accounted for in any other way than by supposing that they derive their low temperature from high mountains from which they had descended, and that, in their quick subterranean course, they have preserved an equal temperature at heights differing often by several thousand feet.

Dalton‡ observed the temperature of a copious spring on

* Gilbert's Annalen, vol xxiv. p. 50.

† Poggendorff's Annalen, vol. xii. p. 413.

‡ Meteorological Essays, or Gilbert's Annal. vol xxiv. p. 50.

Mount Helvellyn, near Kendal, 2700 feet above the sea, and 393 feet below the summit of the mountain, on the 27th August, to be 38°. So low a temperature for a spring rising in such a moderate elevation, in the north of England, is somewhat remarkable.

Von Humboldt* likewise mentions several springs in the mountains of Cumana and Caraccas, whose temperature is much lower than might be expected from their elevation. Hunter's well-known observations on the temperature of springs in Jamaica, afford examples of similar appearances. Humboldt already observed that one of those springs, rising at a height of 3918 feet above the sea, probably derives its very low temperature from the peak which rises to 6966 feet.

That even waters flowing on the surface of the earth, and bearing a temperature very different from that of the atmosphere, change their temperature but very slowly, is particularly evident from the brooks which issue from the glaciers, and which frequently, after a long-continued course, suffer a scarcely perceptible increase of temperature. On the western declivity of the Teutoburger Wald, where such copious springs occur that they immediately form considerable rivers, I also found that one of these rivers, after a course of half a mile, had only become 0°.675 warmer, although the temperature of the air was 22°.5 higher than that of the water.

All these observations shew that springs which descend from great heights bring down cold with them, and, indeed, the more copious they are, the quicker their subterranean course, the steeper the mountains, or the nearer their channels approach the vertical position, and the less they are adulterated on their way with waters of a different temperature, the greater is the degree of cold which accompanies them. From which it follows, conversely, that springs which rise from below, out of various strata of the earth, will bring heat with them, and in a great degree the more the above conditions are fulfilled.

The more the temperature of springs surpasses that of the strata through which they pass, the more they will lose of their temperature. Boiling springs seem only to reach the surface,

* Gilbert's Annal. vol. xxiv. p. 46.

where volcanic fire also shews itself, as, for example, in Iceland,* on the Lipari Islands,† and Las Trincheras near Puerto Cabello, in the Corderillas.‡ But some springs would certainly reach the surface with a higher temperature, did they not meet on their way with colder ones; and springs running in narrow channels must cool more rapidly than in larger ones.

CHAP. V.—*The Temperature of Springs being a function of that of the Meteoric Waters, and of the strata of the earth through which they flow, it is required to determine whether the Variations of the Temperature of the Meteoric Waters also shew themselves in Thermal Springs.*

Springs which only pass through those strata which participate in the variations of the external temperature, must themselves have a variable temperature. The table at the end of the next chapter, which contains my own observations on the temperature of springs, as well as all those of others which have come to my knowledge, affords many examples of such variable springs.

As in our latitude the yearly mean temperature, of the air occurs about April and October, its maximum in July, and its minimum in January, it will be seen by the Table, that the variations of temperature of some few springs keep an equal pace with those of the air. In most cases they follow one, two, or even three months later.§ This depends on the depths below the surface in which the course of those springs lie, the quantity of water they yield, and the power of conducting heat possessed by the soil. The deeper springs flow, the less abundant their waters; and the less degree of conductibility of heat of the soil, the later will the seasons of their temperature follow these of the air. The differences between the annual maximum and minimum temperature of springs are, in general, greater the

* Gilbert's Annalen, vol. xliii. p. 54.

† Poggendorff's Annal. vol. xxvi. p. 67.

‡ Annales de Chimie et Phys. vol. lii. p. 181.

§ In the Journ. de Phys. vol. lxxviii. p. 224, it is asserted that the minimum temperature of springs happens at the time of the maximum temperature of the air, and *vice versa*; for a thermometer, which was suspended in a well of 34 feet deep at Geneva from 1796 to 1805, gave a maximum of 54.275 in December 1804, and a minimum of 48°.425 in June 1798.

nearer their variations of temperature coincide with those of the air, and conversely. The Table shews these differences to be greatest, when the maximum temperature of the springs occurs in July or August, and the minimum in January and February.

In the Table we find that the difference between maximum and minimum most frequently does not amount to $2^{\circ}.25$, and that differences exceeding $11^{\circ}.25$ are of rare occurrence. The greatest difference is $20^{\circ}.25$, with the exception of the springs of Stuttgart and Tübingen. As the temperature of these springs was observed at the outlet of long aqueducts running at a very small depth beneath the surface, it is evident that the temperature of the air must have had some effect upon it. So that, in this respect, the differences of temperature of those springs cannot serve for a comparison.

A singular relation is observed to exist with regard to the annual variations of temperature of the salt springs of Werl. They correspond almost exactly with the variations of temperature of the air; and yet the springs are undoubtedly thermal. If these were produced in the same manner as the very copious springs of the Jordan, Lippe, Pader, Heder, and so forth, which rise on the western declivity of the Teutoburger Wald and the Haar, it would be easy to conceive that their variations of temperature should correspond with those of the air; for those springs are, in fact, rivers, which having sunk from higher regions into the numerous clefts in the chalk rocks, pursue a subterraneous course, and reappear at a much lower level. Such considerable bodies of water, in sinking to a depth where the increase of temperature towards the centre of the earth is perceptible, do not entirely lose the temperature which they had acquired whilst running on the surface; so that, notwithstanding their appearance as thermal springs, the variations of the external temperature still shew themselves in them.*

* Between the variations of temperature and of the contents of salt of these springs no relation can be found. Their mean temperature in 1833 was higher than in 1832; whilst, on the other hand, the quantity of salt contained in them was much smaller. Besides, the maximum of salt contained in them falls constantly in May, whilst the minimum has no determined period. This circumstance indicates a very peculiar, or, I would say, a complicated combination of the subterranean channels at Werl; as does also the fact, that different borings in that neighbourhood, often situated very near to each other, yield sometimes strong salt waters, and sometimes springs of fresh water.

These salt springs prove, therefore, that even thermal springs can participate in the variations of the external temperature. The differences between maximum and minimum are found, however, to diminish, as the mean temperature increases. But for this very reason it is improbable that springs originating in the superficial strata, in which the variations of the external temperature are still felt, should shew a constant degree of heat. Springs of constant temperature must, therefore, always be considered as thermal. The difference between the temperature of the coldest of the constant or nearly constant springs, and the mean temperature of the neighbouring variable springs, is not the same for all places. According to the table, these differences are, for the neighbourhood of Berlin $0^{\circ}.675$; in Sweden hardly $2\frac{1}{4}^{\circ}$; near Burgbrohl, about $2\frac{1}{4}$ miles from Bonn, they rather exceed $4\frac{1}{2}^{\circ}$, and the warmest of the salt springs of Werl, which surpasses the probable temperature of the coldest of the neighbouring springs by $6^{\circ}.075$, is not yet constant, but shews a yearly variation of temperature of $4\frac{1}{2}^{\circ}$.*

It may be that the extent of these differences of temperature at a certain place, depends, in some measure, on its geographical latitude, as, according to Chap. VIII, the depth to which the external temperature continues to be felt, is greater in higher than in low latitudes, the annual variations of temperature of the air being also greater there than here. But the less considerable these variations are, the less are also the yearly variations of temperature of the waters which filter into the earth, and the more easily will they, after a short percolation of the earth's crust, give rise to springs of a constant temperature. The influence of latitude upon the scale of the annual variations of temperature must, however, certainly be very much modified by other circumstances,—namely, the elevation above the surface of the sea at which the springs rise, the filtering of the atmospheric waters in more or less considerable streams through the earth, and the degree of conductivity of heat of the soil. The extent

* From a comparison of the observations on the temperature of a spring in a well sunk in London which was constant, and indicated $53^{\circ}.96$, with the mean temperature of that capital, the difference appears to be for that locality $3^{\circ}.6$ to $4\frac{1}{4}^{\circ}$.—*Annales de Chim. et de Phys.*, vol. xxi. p. 316.

thermal springs—as we have seen in the foregoing chapter—of variable temperature, it cannot be expected that one of the coldest should have a constant temperature. It may, therefore, be assumed with safety, that the mean temperature of a place is always below that of a spring whose temperature is constant at different seasons of the year.

At the first view, it would seem that deep wells were particularly suitable for determining the temperature of the soil. Many objections may, however, be called to mind against this. Von Buch remarks, that only such wells are proper for this purpose as are in constant use, by which their waters are kept continually in circulation; but not such as remain undisturbed, for in them the cold air sinks down from the atmosphere, and cools their walls below to a greater extent than the propagation of heat would allow. Farther, it must be presupposed that such wells are only supplied by waters filtered through the superficial strata of the earth, and that they are so far distant from any mountains of importance, that it can no longer be considered possible for waters to filter down into them from higher and colder regions. But it must also be supposed that they do not receive any tribute from warmer springs rising from a greater depth. If, in sinking a well, a stratum be met with which is impervious to water, and which has no where been broken through, one may be tolerably certain that the latter case has been avoided. A communication with clefts, by which they might be supplied with waters from below, in the manner of artesian wells, is most to be apprehended when a well is cut in the solid rock. Deep wells, which communicate with neighbouring deep rivers, are very likely to hold thermal waters, especially if there be any rising ground between the springs and the river, although it be but a few hundred feet above the bottom of the valley. Thus the temperature of a well of fifty-eight feet under my laboratory, which is in connexion with the Rhine, is almost constant, and is about $1^{\circ}.35$ higher than the mean temperature of the soil here. This spring is consequently thermal. The mean temperature of the soil cannot, therefore, be deduced with certainty from observations on the temperature of wells. An approximate result can only be obtained by extending the observations to many different wells.

If we apply these general conclusions to Wahlenberg's observations, it is easy to perceive that he has determined the mean temperature of the soil at Upsala, at the Ynger See, at Umeo, Söderköping, and Carlscrona, in all cases too high, because he deduced them from observations made either on constant warm (thermal) springs, or on variable springs in months in which they could not possibly have their mean temperature. We must therefore call in question his conclusion, that the mean temperature of the earth in the north is every where higher than the mean temperature of the air, and that the difference between them is greater the higher the latitude, or the colder the winters.

It was shewn in Chap. I. how universally thermal springs are dispersed over the earth. In rocks which are very much dislocated, and in which the atmospheric waters descend to a considerable depth, the number of thermal springs may probably surpass that of the cold ones; indeed, perhaps, scarcely one will be found from which the mean temperature of the soil can be determined. I found this assertion upon numerous observations which I made in April 1833, and May 1834, upon the springs at the foot of the chalk rocks of the Teutoburger Wald, in strata which are very much fissured. In April 1833, I found among sixty-six running fresh-water springs, only three whose temperature was below $47\frac{5}{4}^{\circ}$; all the rest varied from $47\frac{3}{4}^{\circ}$ to $60^{\circ}.6$. In May 1834, the temperature of those three springs had risen $3^{\circ}.6$. As, according to the table, no spring as yet observed, reaches its mean temperature earlier than April, and most springs not until June, and sometimes even July, the mean of those three springs cannot fall below $47\frac{5}{4}^{\circ}$. If it falls above $47\frac{5}{4}^{\circ}$ they may be considered as thermal, for the mean temperature of the air at that place cannot be much above $47\frac{3}{4}^{\circ}$. Another circumstance in favour of this is, that, in May 1834, I found a fourth spring, near those three, the temperature of which was $47\frac{5}{4}^{\circ}$ or $3^{\circ}.6$ colder than the coldest of the others. If this fourth spring observes the same law in the variations of its temperature as the other three do, there is no longer any doubt that they are thermal. There can be no question whatever that the other sixty-three springs are thermal.

Besides those sixty-six fresh-water springs, I observed in May

1834, a great number more in that neighbourhood; and, on similar grounds, I think that I am justified in considering the majority of them as thermal.

In mountains which are split to a great depth, it is therefore possible that scarcely one spring may be found from which the temperature of the soil might be determined. And, even when such is not the case, an approximative idea of the mean temperature of the soil can only be obtained, provided there be no high mountains near, by observing the temperature of a great number of springs in the neighbourhood for at least a year, and taking the coldest among them.

So long, however, as no springs are found whose differences of temperature are in totally different proportions from those in the table, a tolerably correct value may be found for the mean temperature of the soil, from observations on the temperature of single variable springs, if made at a well chosen season, and provided they do not rise out of unusually fissured rocks. For instance, since the mean temperature of springs generally falls in the months of December or January, and in June or July, it is sufficient to observe the temperature of springs only at those times, in order to get a very near approximation to the actual mean temperature of the soil. It may be ascertained still more exactly, by finding out exactly the period of the maximum or minimum of the springs, and observing their temperature three months after that date. The precise period of the mean temperature of springs for each individual case, cannot be determined with such exactitude, as it was for the mean temperature of the air, by the observations made at Leith in Scotland.*

The same objections which we have made to Wahlenberg's determinations of the mean temperature of the soil, are also applicable to the observations of Kupffer† in several parts of eastern Russia, as well as to the conclusions which he was led to draw from them.

Erman jun.‡ finds the temperature of the springs at Königsberg $3^{\circ}.55$ higher than that of the atmosphere. I can only ac-

* Results of the Therm. Obs. made at Leith Fort every hour of the day and night during the years 1824 and 1825, p. 19.

† Poggendorff's *Annalen*, vol. xv. p. 159, and following.

‡ Poggendorff's *Annal.* vol. xi. p. 310.

count for this great difference by supposing the temperature of the air at Königsberg to have been probably determined much too low ; for at Mitau, which lies to 2° farther to the north, and rather to the east, it has been found $1^{\circ}.35$ higher.*

The temperature of the springs near Berlin and Potsdam strengthened Erman *sen. et jun.* in their opinion, that in high latitudes the temperature of the soil is higher than that of the air. They estimate the temperature of the soil at Berlin and Potsdam at $50^{\circ}.07$ to $50^{\circ}.15$, and consequently find, as Humboldt and Tralles ascertained the mean temperature of Berlin to be $46^{\circ}.4$ to $47^{\circ}.3$, that there is a considerable difference between their results.

If the mean temperature of the soil can only be ascertained from the coldest springs (provided there be no high mountains in the vicinity which could send down cold springs into the valleys), and if, without exception, all constant, or nearly constant, springs are thermal, then even the Louisenbrunnen and the spring at Templin must be thermal. With regard to the latter it is the more probable, as it is indebted for its existence not only to the meteoric waters of the neighbouring hills, but seems to take its rise at a much greater distance. The mean temperature of the earth at Berlin is therefore probably below $49^{\circ}.1$, so that the difference is considerably diminished, if not totally annulled. The difference of $2\frac{1}{4}^{\circ}$, mentioned by Erman, between the temperature of the springs in Freienwald and at Neustadt is also a corroboration of this opinion.

From the six years' observations made at Stuttgart on the temperatures of the air and of the springs, it was found that the mean of the latter only surpassed that of the former by $0^{\circ}.427$. It must, however, be observed, that the mean temperature of the air was determined too high, on account of the want of observations made during the night ; but then, on the other hand, that of the springs must also have been estimated too high, as the observations were made at the time of the daily maximum temperature of the atmosphere, and as the wooden aqueduct, which is about a mile in length, lies at a depth of only three feet, and in several places is made to pass through brooks. And if the influence of the daily variations of temperature be no

* Poggendorff's *Annalen*, vol. xv. p. 183.

longer felt at the depth of three feet, as Munke's* observations seem to shew, still heat would be imparted to it by the rivulets through which it passes. It is therefore very possible that the mean temperature of the spring was estimated as much too high as that of the air was.

I must here call attention to another circumstance, which is certainly worthy of notice. Observations on the temperature of the air are generally made in places protected from the direct influence of the sun's rays, as well as from radiated heat; but the soil is exposed to these. The yearly mean temperature of the air must then, if ascertained in such a situation, be lower than the mean of the superficial crust of the earth; but variable springs receive their heat from that external crust, so that their temperature must be higher than that of the atmosphere. Single observations on the temperature of the soil and of the air have given very considerable differences. Thus Humboldt† found the temperature of the air on the Orinoco at two o'clock to be 86° ; that of a coarse moveable granitic sand, $140^{\circ}.45$; that of a similar white, but close-grained fine sand, $126^{\circ}.5$; and that of the granite rocks, $117^{\circ}.725$. An hour after sunset, the coarse sand shewed $89^{\circ}.6$, and the granite rock, $101^{\circ}\frac{5}{8}$. As sand absorbs the heat of the sun in a greater degree than other earths, and as the meteoric waters, filtering slowly through it, easily assume the temperature of the sand, it is very possible that the mean temperature of springs which have their origin in a sandy soil may rise higher than the mean temperature of the air. This may, perhaps, be the case with the springs near Berlin. For that reason, it would be very desirable to combine observations on the temperature of the superficial strata with those made at the same time on the temperature of springs and of the air.

The thermometrical observations at Tübingen were made in a well of running water in the botanical garden. A comparison of the yearly mean of these with the yearly mean temperature of the air, speaks in favour of the opinion that the former is higher than the latter, for they give—

* Gehlers neues Physikal. Wörterbuch, vol. iii. p. 988. Fourier's "*Théorie de la Chaleur*," places this limit at about 3 yards.

† Voyage, vol. vii. p. 203.

		Mean Temperature of the	
		Spring.	Air.
1831,	.	50°.47	48°.65
1832,	.	49°.68	45°.00
1833,	.	49°.23	46°.90

But, if we compare the mean temperature of the springs at Stuttgart with that of the spring at Tübingen, we shall be inclined to suspect that the latter is thermal, for this place lies higher, and in a less mild climate, than Stuttgart, and yet the mean temperature of the spring at Tübingen was somewhat higher than that of the springs at Stuttgart.

The uniform nature of the soil in Basel, out of which rise eight fresh-water springs, in the space of about half an English mile, offers a particularly favourable opportunity of observing the temperature of the earth in that locality. The soil of Basel is covered with considerable deposits of rolled stones, under which there is a bed of marl and clay, falling gently to the north-east towards the Rhine. The meteoric waters, after having filtered through the layers of loose stones, meet with this impervious bed, the gentle slope of which directs them towards the Rhine.

Among these springs the Lochbrunnen, on the Herbrigberg, is remarkable for its low temperature. To my question whether this low temperature might not perhaps be derived from the neighbouring heights of the Jura, Professor Merian answered that such a conjecture could not be borne out by the circumstances of the locality. He is much rather inclined to ascribe the low temperature of that spring to the phenomenon observed by Forchhammer on the Faroë Islands, viz. that those springs which rise out of loose stones are invariably colder than those which rise out of the solid rock at the same elevation. (See a subsequent chapter.) On the other hand, the St Alban Thalbrunnen may be considered as a thermal spring. If these two be excluded and the mean deduced for the rest, we obtain 49°.26 for the mean temperature of the earth at Basel. According to the comparison made by Merian, with the mean temperature of the air at Strasburg, and at Geneva, this value can differ but little from the mean temperature of the air at Basel.

As it was assumed that in high latitudes the temperature of

the earth was higher than that of the air, so it was conversely supposed that in lower latitudes, the mean temperature of the springs was somewhat lower than that of the air. This supposition was founded particularly upon Humboldt's observations between the tropics. But that philosopher himself remarks,* that in steep and high mountains, where either the snow-water quickly mixes itself with lower springs, or where they rise near their origin in lofty regions, the mountain springs show a lower temperature than the mean of the place where they burst forth. He refers for examples of this to the above-mentioned observations in Jamaica, and to his own in the mountains of Cumana and Caraccas. Von Buch† adds to these, similar observations on springs near the Havanna, and in the interior of Congo, and remarks, that the inferior temperature of springs begins to shew itself already in the south of Europe; and that there are probably many springs in Portugal, Spain, and Italy, which differ in their constant temperature from that of the air, much more widely than the springs in tropical countries. Thus, for example, he refers to a spring at St Cesareo, not far from Palestrina, near Rome, the temperature of which he found, on the 29th of August, to be $53^{\circ}.37$, whilst the mean temperature of the air at the same place, is $60^{\circ}.35$. But may not this low temperature have been brought down with it from the neighbouring Apennines, which, in the immediate vicinity, attain a height of 2000 to 3000 feet?‡

It is easy to prove that it is contradictory to the hypothesis of an increase of temperature towards the centre of the earth, to suppose that the temperature of the soil in low latitudes is lower than the mean temperature of the air; for if the temperature of the earth's crust in those regions were lower than that of the air, there must be a stratum at a certain depth, whose temperature would be equal to the mean temperature of the air. Thus the external crust of the earth would be inclosed between two

* Gilbert's Annalen, vol. xxiv. p. 45 and 46.

† Poggendorff's Annal. vol. xii. p. 407.

‡ From a personal communication of Professor Hoffman, I have learned that a great number of springs in the deep valley of Teverone, between Tivoli and Subiaco, are remarkable for their low temperature, which amounts on an average, to from $47\frac{3}{4}^{\circ}$ to $52\frac{1}{4}^{\circ}$.

strata, the one of air and the other of earth, both of which would be warmer than itself. A permanently low temperature of the external crust can be conceived in no other way, even considering it to be a much worse conductor of heat than it really is, than by supposing the existence of a never-failing cooling principle; but, then, what could that principle be? Such an hypothesis is shewn to be still more contradictory by the above-mentioned observations of Boussingault; namely, that, between the Tropics, the temperature of the earth is constant at the depth of one foot below the surface. For how can it be supposed that the crust of the earth should, at the depth of one foot from its surface, have a constant temperature lower than that of the air, with which it is continually in contact? But that supposition is most completely refuted by Boussingault's comparative observations, as will be seen from the following table:

	Mean Temp. of the Air.	Temp. of the Soil, one foot below the Surface.
Zupia, ...	80°.375	80°.37 to 80°.60
Mines of Marmato, . . .	78°.125	77°.67 to 78°.12
Anserma Nuovo, ...	85°.55	85°.10 to 85°.55
Popayan, ...	74°.075	72°.95
Pasto, ...	64°.85	65°.07
Quito, ...	66°.987	66°.42 to 66°.87

Between 5° south and 11° north latitude, the mean temperature of the air exactly accords with the temperature of the earth, taken at one foot below the surface of the earth, in a place protected from the sun by a roofing.

In order to obtain a similar comparison in the temperate zones, it would be very desirable that similar observations on the temperature of the soil should be made in our latitudes which, however, it would be necessary to continue for at least a year. Till now, little has been done towards this object. According to the observations of Rudberg, the mean temperature of the earth at Stockholm is 1°.62 higher than that of the air. Three years' observations, conducted by Herrensneider at Strasburg, gave the mean temperature of the air 0°.54 higher than that of the soil. The mean of each year, however, differed as much as 1.665 one from the other. It is, therefore, necessary for the comparison that the observations on the air and on the soil

should both be made in the same year. For this reason, no importance can be attached to the above differences.

Taking all circumstances into consideration, we find that there are grounds for assuming, that in high latitudes the earth has a higher, and in low latitudes a lower, temperature than the mean temperature of the air. The springs in high latitudes which led to this assumption were, therefore, without doubt, thermal, that is to say, springs which receive their heat from the interior of the earth. On the other hand, those springs which led to the conclusion that in low latitudes the temperature of the soil is lower than the mean temperature of the air, seem to have been mountain-springs, which brought down their lower temperature from higher regions. Boussingault remarks in general, that in the Cordilleras there are often no springs to be met with for a distance of several hundred miles. Wherever he did find any, for example at Santa Marta and at Cartagena, their temperature exactly corresponded with the mean temperature of the air. It is, therefore, the more plausible to suppose, that the few springs of which the temperatures have been determined in those countries, have only been found in mountainous districts.

Kupffer's *isogeothermal** lines, drawn through all points of the earth's surface which have an equal temperature of soil, an imitation of Humboldt's *isothermal* lines, lose their importance in consequence of the above considerations, as, in general, *isogeothermal* and *isothermal* lines coincide.

There is, however, no doubt that differences will here and there be found between the mean temperature of the air and that of the soil. Thus, in valleys which are surrounded by high and steep mountains, the temperature of the soil may be rendered lower by springs which bring down cold from above. In this case, the mean temperature of the air will be higher than that of the earth. The severe climate of certain mountain-valleys may perhaps proceed from this. In like manner, as the highest mountains on our globe are situated for the most part in low latitudes, it is to be expected that the temperature of the earth would there be lower than the mean temperature of the air, rather than in high latitudes. Thus the hypothesis of a

* Poggendorff's *Annalen*, vol. xv. pp. 190 and 183.

lower temperature of the springs than of the air, may hold good for several points in the mountainous parts of the torrid zone.

On the contrary, the temperature of the soil will be raised if the rocks be so fissured and cleft as to admit of the rising of thermal springs. If such waters rise in considerable quantities, and with a great heat, they may cause the temperature of the earth to rise perceptibly above the mean temperature of the air. Thus, the temperature of the soil at Aachen and Burtscheid, where waters of 90° to $112^{\circ}.5$ higher than the mean temperature of the air spring up in large quantities, is probably higher than that mean. The same may be expected at Paderborn, where, according to my measurements, more than a million pounds of water are ejected in a minute by all the Padersprings together, which are $6^{\circ}.75$ warmer than the mean temperature of the air. The earth's crust being cleft to a great depth, and thus allowing warm springs to rise, may therefore cause an elevation of the temperature of the soil.

But the temperatures of the soil and of the air must by no means be invariably considered as identical. Copious springs, heated to any degree above or below the mean temperature of the air, and rising in great numbers, communicate their temperature to the strata through which they flow. Single and scantily supplied springs can, however, cause but trifling alterations. The above-mentioned springs in the Teverone valley, between Tivoli and Subiaco, whose temperature is only $47^{\circ}.75$ to $52^{\circ}.25$, and whose number is very great, although they yield but little water, must certainly tend but slightly to cool the earth, for in this valley all the products of middle Italy, as the vine and the olive, flourish most luxuriantly.

There is another phenomenon, which, although it is only local, must not escape notice. It is well known that in certain places there are cavities beneath the surface, in which there is ice both in summer and winter. The mean temperature of the ground in such caverns cannot be above 32° , whilst that of the atmosphere may be much higher. This is not the place to examine how such natural ice cellars are caused; it is only necessary for us to point out their frequent occurrence.

If we do not confine ourselves to places where there is ice

throughout the year below the surface, but include all places of which the mean temperature is lower than that of the surface (and in fact they only differ from the former as to the degree), we shall with a little attention easily increase their number.

De Saussure* has made us acquainted with several subterranean caverns out of which wind issues, which is colder than the mean temperature of the soil, namely, the caverns of Monte Testaceo near Rome; the Ventarola della Funera on the island of Ischia, which lies still more to the south, and is so entirely volcanic, and full of hot springs; the caves of St Marino and of Cesi; the Cantines of Chiavenna; the caverns of Caprino on Lake Lugano; the cold grottos of Hergisweil, near the lake of Lucerne, and so forth. It is true De Saussure only gives us single observations of the temperature of these caverns, made in the summer months; but the observations of Nollet in the grottos of Monte Testaceo were made in September. These seem to shew that the yearly mean temperature of those winds is much lower than the yearly mean temperature of the air, and that their temperature rises as the seasons advance.

In the Saxon Erzgebirge, Reich† mentions three points which are remarkable for their low temperature. The Heinrichssohle in the Stockwerk at Altenberg was found by two years' observations to have a mean temperature of $0^{\circ}.54$ colder than that of the surface, although situated at a depth of 400 feet. In the Henneberger Stolln (Adit of Henneberg) on the Ingelbach near Johanngeorgenstadt, Reich found the temperature about $0^{\circ}.54$ lower than in the Gnade Gottes and Neujahrs Maassner shaft some hundred feet higher. The Weiss Adler Stolln on the left declivity of the valley of the Schwarzwasser above the Antonshütte, is also remarkable for its extraordinary cold.

Reich‡ has also communicated some interesting observations on the perpetual ice in the mines of the Sauberg, at Ehrenfrie-

* Voyages dans les Alpes, vol. v. p. 342, with remarks by Nicholson, in his Journal of Nat. Philos. &c. No. 5, 1797, in Gilbert's Annalen, vol. iii. p. 201.

† Beobachtungen ueber die Temperatur des Gesteins in verschiedenen Tiefen in den Gruben des Sächsischen Erzgebirges, in den Jahren 1830—1832, &c. Freyberg 1834, p. 200 and following.

‡ 75, and following.

dersdorf. He determined the mean temperature of the surface of the Sauberg at $44^{\circ}.94$. The result of several years' observations in the St Christoph shaft, which lies to the west, and is the least opposed to the cold, was $42^{\circ}.22$, at thirty-one feet below the surface; the same temperature was found in the Morgenröther cross-cut, lying to the east of this shaft, at a depth of 281 feet from the surface. The temperature is, then, considerably lower than the mean temperature of the surface, as well near the surface as at a greater depth. In the Sauberg the ice is seldom found lower than fourteen fathoms; however, it was once observed in the interstices of the Old Man, as much as twenty-four fathoms below the surface. Reich found the temperature of the ice to be $31^{\circ}.982$, the air in the immediate vicinity $34^{\circ}.025$, and the rock at a little distance $32^{\circ}.765$.*

At many other places, in the Erzgebirge, the temperature of the soil was found, on the contrary, to be higher than that of the air, viz. :—

	Soil.	Air.	Difference.
Altenberg, ...	$42^{\circ}.732$	$41^{\circ}.270$	$1^{\circ}.462$
Markus Röhling, . .	$43^{\circ}.542$	$41^{\circ}.832$	$1^{\circ}.710$
Johanngeorgenstadt, .	$43^{\circ}.115$	$41^{\circ}.090$	$2^{\circ}.025+$

At Markus Röhling the temperature of the soil, as well as of the air, is remarkably low, in comparison to its elevation above

* For further information on ice-caverns and ice-grottos, see Gehler's Neues Physik Wörterbuch, vol. iii. part i. p. 150, and following; and Reich, p. 188, and following. It is related of several such ice-grottos, that the ice is only there in summer, and that it thaws away in winter. By referring to the three years' observations on the temperature of the St Christoph shaft we find that the maximum occurs in November, and the minimum in April; so that the opinion that the mines are colder in summer than in winter is easily accounted for. If a spot could be found, whose mean temperature was exactly 32° , ice would be found to continue to increase there till June or even July; and on the other hand, to decrease until December or January. But the one would nevertheless be the effect of the preceding winter, and the other that of the preceding summer. Also, according to the observations of Dr Oudot (Journ. des Mines, t. iv. No. 21. p. 65), the ice in the celebrated cavern of Besançon, near La Chaux, increases till April, and decreases till October: in January the temperature falls to $20^{\circ}.\frac{3}{4}$, in summer it rises to $38^{\circ}.\frac{3}{4}$. We see, then, that these variations correspond very nearly with those observed in springs, which is nothing else than might be expected.

† Reich, p. 122.

48 *On the Temperature of Hot and Thermal Springs.*

the sea ; the cause of both must probably lie in the locality. The conclusion drawn by Reich, from the above observations, viz. that, in the Erzgebirge, the temperature of the soil is throughout $1^{\circ}.8$ higher than the mean temperature of the air, seems, however, to be somewhat too hazardous.

All these facts prove that great differences may exist between the mean temperatures of the air and of the soil ; but that they only originate in local causes, and do not stand in any relation with the geographical latitude of the place.

CHAP. VII.—*Do the rains and meteoric waters cause greater variations in the temperature of the soil than in that of the air ?*

The winter rains between the tropics being supposed to have the effect of cooling the springs in those regions, I made some experiments in order to ascertain to what extent such a depression might possibly proceed.

The mean temperature at *Cumana*, according to Don Faustin Rubio,* is 82°.09 F.†, the minimum being in January 80°.35, and consequently their difference 1°.73. Supposing the temperature of the air at *Cumana*, in the beginning of the rainy season, to be at the mean or even below it ; if the rains be still colder, they must cool the air until the equilibrium be restored. But the rains will cool the earth's crust, so far as they penetrate into it, sooner than they will the air : and, after some time, both the air and the earth will assume the temperature of the rains. In order to be able to observe the progress of the changes of temperature in the air and in the soil, I made the following experiments.

I placed a thermometer in a glass cylinder 20 inches high, and suspended in it a second, in such a manner, that the bulb was 10 inches above the bottom of the cylinder. This thermometer was protected by a small bell-glass, which was so luted on to it, that the bulb just appeared below its edge. The thermometer at the bottom shewed 70°.70 ; that suspended in the air, 69°.8. I then let the water of 54°.50 fall in a fine shower into the cylinder, and quickly observed the following alterations of

THERMOMETER

In the air, . .	69°.8	67°.55	66°.20	61°.25	59°.9	59°.0
On the bottom, .	70°.70	59°.9	59°.45	58°.55	58°.55	58°.32

At this moment I was obliged to interrupt the experiment, as a drop of water had spirted on to the bulb of the suspended thermometer and caused the mercury to fall to 58°.55. Had this not happened, there is no doubt that the thermometer in the air would soon have fallen as low as the one on the bottom of the cylinder. Similar changes must take place in the earth and air during the fall of rains.

* Annal. de Chimie et de Phys. vol. xxii. p. 303.

† We again remind the reader that the degrees in this memoir are according to Fahrenheit's scale, excepting where otherwise stated.

Now, if the cooling of the soil keeps even pace with that of the air during the winter rains, and if the only difference is, that the former is somewhat in advance of the latter, the yearly mean temperature of the soil can be depressed but imperceptibly below that of the air by this cause. When the winter rains cease, the temperature of the air soon begins to rise again; but the earth remains longer at its lowered temperature on account of the evaporation. This lower temperature may perhaps last rather longer than that caused by the rains, and consequently cause a more considerable depression of the mean temperature of the soil below that of the air. The extent of the depression caused by these two circumstances might be determined, by observing the temperature of the air, the earth and the rain water, during, and a short time after, the fall of cold winter rains.

If the mean depression of temperature during the rainy season is equal to the difference between the mean temperature of the air and that of the rain water, that depression cannot, at *Cumana*, exceed 1.73. The difference then between the mean temperatures of the air and of the soil, during this season, can be but a small fraction of that quantity, and must, therefore, be exceedingly small. And, although single showers may lower the temperature considerably, (Von Humboldt*) for example, observed a fall of 48.20F. during a shower at *Cumana*, the cooling of the air and of the soil will nearly keep equal pace together.

It seems strange that rains falling from cold regions of the atmosphere, should only cause a yearly depression of temperature in the air of at the utmost $2^{\circ}.92$.† But when we consider that rain-drops, at the moment of their condensation, assume a higher temperature than that of the surrounding medium, by the release of latent heat, and that, in their descent, aqueous vapours are condensed upon them, the latent heat of which, becoming free, also tends to raise their temperature; we can no longer be surprised at that phenomenon. Besides, the smaller quantity of heat received from the sun, during the tropical winters, has also some share in causing that difference of 2.92 .

* Voyage ix. p. 20.

† This is the difference between the mean temperatures of the hottest and of the coldest month at *Cumana*.

According to Chap. V, the temperature of springs is a function of the temperatures of the meteoric waters, and of the soil through which they flow. The modifications caused by the temperature of the earth on that of the meteoric waters, depends upon—

1. The capability of the strata to receive the percolating waters, which causes a shorter or longer detention of them in those strata.
2. The capacity of the channels through which the waters flow ; and
3. The capacity of heat of the strata.

If the earth be very much cleft, as is the case with the chalk rocks, and if the fissures be of inconsiderable width, the temperature of the percolating waters will be little altered ; if, on the other hand, the clefts be few and considerable, or the soil be composed of an earth, such as sand, which easily allows the passage of water through it, that temperature will be considerably modified.*

In order to have an idea of the probable effect in one of these cases, I made the following experiments :—

I allowed water to filter through a bell glass 14 inches high and 4.75 inches in diameter, filled with fine sand of the lignite formation. The temperature of the water which was poured upon the sand, and which filtered through it, as well as the temperature of the sand itself, was observed from time to time, before and during the experiment, with very sensitive and perfectly harmonizing thermometers ; and the following results were obtained :—

First Series of Experiments with Sand moderately Damp.

Time	—	4	12	18	20	27	32	34	47	62m
Water	70°.25	76°.55	—	76.10	75°.65	—	75°.20	—	73°.85	72°.27
Sand	40.35	—	60.57	63.95	67.77	69.8	—	71.37	71.60	71.37
Water filtered through }	—	—	—	—	63.27	61.92	—	62.15	62.82	63.27

* Thus it has been found, that, in the chalk rocks, even thermal springs may bear signs of the influence of the external temperature ; as, for example, the salt springs at *Weri*, mentioned in the preceding chapter. On the other hand, in a sandy soil, where the meteoric waters are very much divided, and come in close contact with the particles of sand, the influence of the external temperature is no longer perceptible, at a very moderate depth. For this reason, springs rising through sand shew such small variations of temperature ; as is the case with the springs in the neighbourhood of *Berlin* and *Potsdam*.

yearly fall of meteoric water on the district drained by this brook filters into the earth, and serves for the production of springs.

The results of the above series of experiments, shew the variations of temperature, when meteoric waters only filter to the depth of fourteen inches, and then immediately rise again as springs. It is evident that the influence of the temperature of the meteoric waters on that of springs must decrease in proportion to the depth to which they filter into the earth. If the quantity of water absorbed by a certain surface, during a certain period of time, and farther, the depth to which it sinks, the capacity of heat of the soil, and the mean difference between the temperature of the meteoric waters and the strata which receive them, be known, the variations of temperature caused in the earth's crust by the meteoric waters during a certain period, may be calculated from those data. For these variations of temperature, which take place after a certain length of time, are the same which would ensue, if the whole quantity of water were to sink to the given depth into the earth in a moment. Since the scale of the yearly variations in the temperature of springs evidently depends on the depth from which they rise, this depth may be learned from a knowledge of that scale. Supposing that springs issue with the temperature of the lowest point to which the meteoric waters have sunk, the depth at which the same scale of variations of temperature prevails, as that of a certain spring, may be found by observing the temperature of the earth, at different depths, in the vicinity of that spring. Thus, for example, a thermometer in the *Göpel* shaft of the *Trappe* coal-mine, near Welter, in the *Grafschaft Mark*, gave only $0^{\circ}.83$ as the greatest difference of temperature, at a depth of 26.5 feet,* from which the origin of a neighbouring spring, having the same scale of variation of temperature, may be easily deduced. And such a deduction will, in most cases, be very near the truth; for meteoric waters, filtering in fine drops through the earth, and through the narrow fissures and clefts in the rocks, assume the surrounding temperature the more nearly the deeper they sink. But if, on reaching the lowest point of their course, they unite themselves with another more

* Poggendorff's Annal. xxii. p. 520, table.

or less abundant spring, and are brought to the surface by an impervious stratum, or by hydrostatic pressure, the change thereby operated on their temperature will be the less considerable the more copious they are, and the more quickly they flow. We will suppose, for the sake of example, the mean depth from which a certain number of springs, belonging to a certain district, rise to be thirty feet. Farther, let the specific gravity of the soil be taken at 1.5, and its capacity for heat 0.22, the specific gravity and the capacity for heat of water being taken as unity.* Supposing the height of water providing a certain surface for the supply of its springs to be one foot (about as much as we found in the district of the *Brohlbach* above mentioned), we shall have the proportion between the masses of the water and earth, which come in contact with each other, as 1 : 45. Lastly, let the meteoric waters during a whole year be 11°.25 colder than the soil, and let the mean temperature of the latter be 63°.50. Under these circumstances, if the whole quantity of water were to fall, in one moment upon the earth, the temperature which the earth would assume would be

$$= \frac{1 \times 1 \times 38.75 + (45 \times 0.22 \times 50)}{1 \times 1 + (45 \times 0.22)} = 48.96.†$$

This would consequently also be the temperature which springs, coming from a depth of thirty feet, would have.

Thus, even in case the temperature of the meteoric waters throughout the year, were 11°.25 colder than that of the soil, and that they should only sink to a depth of thirty feet, the temperature of the soil, and consequently also of the springs rising out of it, would still only be lowered 1.035. But these conditions will with difficulty be satisfied either between the tropics, or at any other point on the surface of the globe. And supposing they were satisfied, the difference thereby produced between the mean temperature of the air and that of the soil, would fall far short of 1.035, because the cooling of the air by the meteoric waters would follow but shortly after that of the earth's crust.

* These I found to be the specific gravity and capacity for heat of the sand used in the above experiments.

† Let M and m represent the two masses, S and s their capacities for heat ; T and t their temperatures : the temperature T of the two bodies after their intermixture will be

$$= \frac{MST + mst}{MS + ms}$$

The meteoric waters must also have as little power sensibly to raise, as they have to depress, the temperature of springs. It is, therefore, equally inadmissible, that the temperature of springs, in low latitudes, should be sensibly depressed by the coldness of the winter rains, as that, in higher latitudes, it should be raised by the warmth of the rains in summer.

In the *dislocated* rocks of limestone and quader-sandstone, the relations may prove somewhat different. The fissures in these rocks being for the most part of great depth, the meteoric waters flow through their spacious channels in torrents; the influence of the waters on the temperature of the outer crust of the earth, may, therefore, be much more considerable in these rocks. But the changes effected on the temperature of the earth will still take place, but a short time before those caused in the air.

In order to form an idea of the extent of the influence of these circumstances, I chose the quader-sandstone and chalk-rocks, on the western declivity of the *Teutoburger Wald*, which are fissured to an extraordinary extent, for the theatre of my observations. Many considerable brooks rise out of these rocks, but are for the most part lost in the clefts, and reappear at the foot of the chain. I measured the waters of the *Lippe*, the *Raute*, the *Pader*, the *Alme*, and the *Heder*, and traced the boundaries of the districts drained by them, and found that nearly two feet of the meteoric waters falling in these districts are expended in the supply of those streams.* Here, then, almost twice as much of the meteoric waters sink into the crust of the earth, as in the district of the *Brohlbach*, which is so unusually rich in mineral springs.†

* The *Pader* I measured at the end of May 1834, when it had not rained for a long time. The *Lippe* and *Alme* were measured by Dr Pieper of *Paderborn*, at my request, in the middle of July, which was remarkable for the unusual dryness of the weather, as indeed was the whole summer of 1834. It must, however, be observed, that the *Lippe* loses little of its water in summer; but that the *Alme*, on the contrary, was very much reduced at the time of the measurement. The copiousness of these rivulets was, therefore, certainly not determined too high.

† In a few parts of *Germany*, where the annual fall of rain is known, does there fall a sufficient quantity to supply the springs, which rise on the western declivity of the *Teutoburger Wald*? At *Coblence*, *Manheim*, *Stuttgart*, *Tübingen*, &c., the yearly fall of rain amounts only to from 20 to 23 inches; at *Carlsruhe*, *Giengen*, *Ulm*, *Genkingen*, 24 to 35 inches. See *Kämtz Lehrbuch der Meteorologie*, vol. i. p. 458 and following.

But the deeper the clefts, the nearer will the temperature of the water coincide with that of the rock. And lastly, if the waters reach the regions where the increase of temperature towards the interior of the earth becomes sensible, the springs resulting from them must be thermal. This, as already mentioned, is the case with the most springs rising in the *Teutoburger Wald*. The influence of the external temperature, then, diminishes in proportion as the thermal springs exceed the mean temperature of the air. It is however easy to conceive, that water, sinking through the wide channels in the dislocated chalk rocks, into the regions where the increase of temperature towards the centre of earth begins, should reappear, in a lower situation, as a thermal spring; but should, nevertheless, shew the variations of the external temperature, as seems to be the case with the salt-springs of *Werl*, already alluded to more than once.

CHAP. VIII.—*To what depth in the crust of the earth does the influence of the external temperature continue to be felt?*

The depth to which the external temperature continues to exert its influence upon the crust of our globe cannot be the same at all points. It depends, in the first place, upon the extent of variation of temperature of the air, for the less such variation is, the less considerable will be that depth, and vice versa. Therefore the depth will vary in the same place, the extent of annual variation of temperature of the air being in the various years also various. It depends, further, on the conductivity of heat of the earthy and rocky strata composing the crust of the earth. The former of these circumstances varies according to the geographical latitude of the place and its elevation above the sea, for the nearer to the equator, and the more elevated above the sea, the less, in general, are the variations of temperature. The latter is naturally dependent solely upon local geognostical circumstances.

Between the tropics, from 11° N. Lat. to 5° S. Lat. the depth to which the external temperature continues to be felt, is scarcely so much as 1 foot; for, according to Boussingault's * observa-

* *Annal. de Chim. et de Phys.* vol. liii. p. 225, and following. In the same manner Sir Thomas Brisbane determined the temperature of the soil at *Paromatta* (New South Wales). See *Edinb. Phil. Journal*, x. 279.

tions, thermometers, placed in holes of 8 to 12 inches deep, protected from the rays of the sun by a roofing, shewed variations of at most but a few tenths of a degree. De Saussure* found in a medium latitude that at the depth of 29.5 feet there was still a variation of $2^{\circ}.25$ Fahr. It must, however, be remarked, that this observation was made in a well, where the influence of the temperature of the atmosphere was not precluded. Arago found at *Paris* that a thermometer did not remain constant at a depth of 25 feet below the surface. Indeed, at a depth of 86 feet, a yearly variation of $1\frac{9}{8}$, or 0.0703 of Fahr. was observed. However, the observations made at *Paris* on the 20th July 1825, by sinking thermometers to different depths into the earth, shew that the direct influence of the external temperature, that is to say, independently of the temperature of the air, does not extend much below 25 feet. It was found, namely, that at a depth of

$1\frac{1}{2}$ feet	the temperature was	$82^{\circ}.06$
3		$72^{\circ}.19$
6		$62^{\circ}.5$
10		$57^{\circ}.9$
20		$52^{\circ}.76$
25		$52^{\circ}.49$
86 (in a cellar) .		$53^{\circ}.14$

whilst a thermometer in the shade shewed 91.4, and another immersed in sand shewed, in the sun, 127.4.† D'Aubuisson estimates the depth in question at between 46 and 61 feet, and Kupffer‡ at 77 feet below the surface.

The determination of this depth is extremely difficult, as in wells, shafts, and caverns, it is scarcely possible thoroughly to prevent the influence of the external temperature; whilst the sinking of thermometers to considerable depths into the solid rock, or into the earth, and the observing of their temperature, is hardly practicable.

* *Voyages III.* in the *Bibliot. Britann.* viii. 341.

† *Annal. de Chim. et de Phys.* vol. xxx. p. 398.

‡ In a late memoir in Poggendorff's *Annal.* vol. xxxii. p. 270, Kupffer expresses his opinion that all points of the interior of the earth, of which the greatest variation of temperature is 0.36, are situated at the same depth, whatever be the variations of temperature at the surface. He calculates this depth for points near the equator at 25,2 feet, and for the polar regions at 35,5 feet. This is contradictory to theory, as well as to the actual observations made by Boussingault between the tropics.

It has been found, from thermometrical observations, made in various *Prussian* mining establishments, situated between 50° and $51^{\circ}.5$ N. Lat.,* that, notwithstanding the numerous precautions employed to isolate the thermometers placed at different depths from the atmosphere, they still, in some cases, shewed great irregularities of temperature, as will be seen from the following table ;

Depth below the surface at which the observation was made.	Greatest differences of temperature observed.	Depth below the surface at which the observation was made.	Greatest differences of temperature observed.
27 Paris ft. .	0.83 F.	55 Paris ft. .	6°.19 F.
32 — .	1°.8	33 — .	6°.75
32 — .	2°.25	45 — .	10°.13
63 — .	2°.25	29 — .	12°.60
28 — .	2°.81	155 — .	0.0
26 — .	3°.37	159 — .	0.0
32 — .	5°.29		

From this we see, that in the temperate zones the influence of the external temperature may be no longer perceptible at the moderate depth of 27 feet ; but that, under less favourable circumstances, it may be more or less considerably felt at depths of 55 and 63 feet, or even more ; and, lastly, that at 155 and 159 feet it entirely disappears.

In the years 1830–1832, observations were made with great care in the mines of the *Saxon Erzgebirge*, on the temperature of the rock at various depths.† In order, if possible, to avoid the effects of a change of air, thermometers were used of such a length, that the bulbs might be sunk 40 inches deep into holes bored in the rock, whilst the scale might be observed from without. The spaces between the thermometers and the sides of the holes were filled with dry sand. The scales were divided to tenths, by which the observations might be taken in hundredths of a degree centesimal. The utmost care was bestowed on the graduating and harmonizing of the thermometers.

In choosing situations for the thermometers, points subject to considerable draughts of air, and such as were occupied by

* Poggendorff's Annal. vol. xxii. p. 520.

† Beobachtungen ueber die Temperatur des Gesteins in verschiedenen Tiefen in den Gruben des *Sachsischen Erzgebirges* in den Jahren 1830 bi. 1832, zusammengestellt von F Reich. Freyberg. 1834.

workmen, were as much as possible avoided. They were always placed in the solid rock, and in spots above which there were no halvens or other heaps of rubbish. The holes were bored in such a manner, that the bulbs of the thermometer should lie at least 40 inches below the surface of the rock, and only such were used as were free from wet.

During his observations on the hourly variations of the magnet, Reich had an opportunity of observing the rapidity with which the air operates upon the rock even at a distance of 40 inches. The air in the mine shewed $48^{\circ}.6$ with but slight variations, and a thermometer sunk into the rock $48^{\circ}.64$; but when, after 44 hours' observation of the magnet, the temperature of the air had been raised by the presence of the observers, and their two candles, to $49^{\circ}.7$, the thermometer in the rock, which was subject to no change of air whatsoever, was found to have risen to $48^{\circ}.71$, $48^{\circ}.73$. This discovery destroyed all hope of obtaining the temperature of the rock, quite free from the influence of the air, by sinking the thermometers even 40 inches deep into the rock. In order to ascertain whether the temperature of the rock was raised or depressed by the air, at different points near the scale of the thermometer sunk into the rock, were placed others exactly corresponding with it. Thus, if the mean temperature should be higher than that of the rock, it might be concluded that the air tended to raise the temperature of the rock; and if lower, that it caused a depression. They were, however, satisfied with knowing, whether an increase or decrease took place, without determining to what extent it was carried. The observations frequently led to no results. The thermometers near the surface were generally observed three times a-week; those situated further down, twice. Reich estimates the errors of observation in some cases at 0.18.

Another observation, which proves how deep in the earth a change of temperature in the neighbourhood, although small, if it be but of long duration, may be felt, is worthy of notice, as it shews how many unknown, as well as known circumstances, may have influenced former thermometrical observations in mines, and how little the want of concord in the results obtained from them is to be wondered at. In the mine of *Beschert Glück*, in the *Freyberg* district, a thermometer buried in the

disintegrated gneiss, forming the floor of a cellar under a smithy, showed, in 1830, a mean temperature of $49^{\circ}.79$, which was much too high, compared with other observations made at the surface. This was caused by the strong fire in the smithy, the greatest proximity of which to the thermometer was 12 feet.*

I have reduced the centesimal degrees of the observations, made near the surface, at various places in the *Saxon Erzebirge*, into degrees of Reamur, and arranged them in the following table. The numbers represent the monthly mean temperature. Reich also gives the maximum and minimum of each month; but these I have omitted for shortness' sake, and have confined myself to noting, in the four last lines, the greatest yearly differences of temperature, which is of the most importance for our object. The places of observation are arranged in the order of their depth below the surface; but their elevation above the sea is at the same time marked.

Depth below } the Surface } Elevat. above } the Sea }	5'.5	17'.2	22'.2	23'.4	23'.1	30'.8	33'.9	34'.8	47'.7	52'.9	94'.3	121'.3
	1009'	2493'	945'	1440'	1381'	1718'	1754'	2322'	1395'	1431'	1447'	1322'
1830.												
January .	4.43	...	5.03	5.66	...	...	...	...	...	...	...	7.25
February .	3.57	...	4.38	5.19	...	...	...	...	...	...	...	7.25
March .	3.82	...	4.01	4.67	...	...	...	...	...	...	...	7.24
April .	4.88	...	4.44	5.04	...	...	...	...	...	...	...	7.26
May .	6.00	...	5.54	5.72	...	...	...	...	...	...	...	7.26
June .	7.29	...	6.86	6.58	...	...	...	...	...	...	...	...
July .	8.32	...	8.08	7.36	...	3.91	...	...	...	...	6.81	...
August .	9.26	...	9.09	8.28	...	4.22	...	...	...	...	6.83	...
September .	9.22	...	9.09	8.23	...	4.67	...	...	...	...	6.86	...
October .	8.51	5.47	8.52	7.89	7.26	5.29	5.26	...	7.26	6.41	6.86	7.25
November .	7.79	5.47	7.73	7.27	6.98	5.46	5.22	...	7.09	6.52	6.86	7.25
December .	6.88	5.39	6.57	6.60	6.58	5.20	5.24	...	6.93	6.39	6.88	7.24
1831.												
January .	5.77	5.10	5.42	5.85	6.21	4.87	5.28	4.25	6.81	6.34	6.86	7.26
February .	5.02	4.84	4.68	5.39	5.98	4.14	5.20	4.04	6.66	6.61	6.87	7.26
March .	5.02	4.56	4.37	5.23	5.94	3.46	5.11	3.99	6.71	6.71	6.86	7.28
April .	5.27	4.26	4.86	5.41	5.99	3.25	4.97	4.22	6.82	6.70	6.83	7.29
May .	5.95	4.06	5.89	6.09	6.13	3.40	4.85	4.78	6.99	6.69	6.85	7.29
June .	6.71	4.21	6.93	6.72	6.43	3.54	4.86	5.34	7.14	6.66	6.85	7.29
July .	7.55	4.67	8.31	7.50	6.98	3.80	5.00	5.94	7.26	6.62	6.86	7.29
August .	8.18	5.32	9.14	8.08	7.66	3.99	5.21	6.46	7.42	6.58	6.87	7.29
September .	7.82	5.63	9.24	8.13	7.61	4.76	5.31	6.25	7.43	6.56	6.88	7.29
October .	7.46	5.90	9.00	7.93	7.66	5.34	5.42	6.26	7.38	6.67	6.89	7.29
November .	6.22	5.94	8.25	7.48	7.30	5.65	5.54	5.18	7.38	6.74	6.90	7.30
December .	5.02	5.75	6.98	6.80	6.87	5.40	5.50	4.49	7.21	6.81	6.89	7.31

* Perhaps also the water used for quenching and hardening may have found its way to the spot where the thermometer was placed.

Depth below the Surface } 5'5	17'2	22'2	23'4	23'1	30'3	33'9	34'8	47'7	52'9	94'8	121'3
Elevat. above the Sea } 1009'	2493'	945'	1440'	1381'	1718'	1754'	2322'	1395'	1431'	1447'	1322'
1832.											
January . . .	5.47	5.86	6.06	6.43	4.86	5.60	4.3	7.13	6.79	6.35	7.32
February . . .	5.08	5.16	5.56	6.23	4.59	5.50	3.95	7.10	6.79	6.35	7.33
March . . .	4.78	4.62	5.22	6.11	4.40	5.42	3.66	7.10	6.80	6.78	7.34
April . . .	4.48	4.78	5.10	6.13	4.14	5.32	3.87	7.12	6.84	6.84	7.36
May . . .	4.36	5.51	5.65	6.18	3.98	5.23	4.33	7.11	6.87	6.84	7.36
June . . .	4.45	6.90	6.38	6.50	3.90	5.16	5.14	7.20	6.87	6.83	7.37
July . . .	4.77	7.86	7.00	6.93	4.11	5.19	5.79	7.46	6.86	6.80	7.39
August . . .	5.27	8.58	7.46	7.56	5.16	5.28	6.15	7.57	6.82	6.81	7.41
September . . .	5.58	8.83	7.96	7.67	6.07	5.44	6.10	7.58	6.75	6.84	7.42
October . . .	5.73	8.16	7.83	...	5.94	5.55	5.78	7.58	6.74	6.86	7.41
November . . .	5.68	7.22	7.14	...	6.10	5.62	4.59	7.58	6.74	6.86	7.41
December . . .	5.50	6.25	6.34	...	5.82	5.59	4.31	7.47	6.73	6.86	7.42
Mean 1830	6.66	4.92	6.61	6.54	...	4.28	5.13	...	7.05	6.57	6.86
Mean 1831	6.34	5.02	6.92	6.72	6.65	4.30	5.16	5.10	7.10	6.64	6.87
Mean 1832	...	5.10	6.65	6.47	6.80	4.92	5.41	4.83	7.34	6.80	6.83
Mean in gen.	6.50	5.05	6.73	6.58	6.72	4.54	5.23	4.97	7.22	6.70	6.85
Differ. 1830	6.10	1.78	5.30	3.90	...	2.37	0.58	...	0.55	0.10	0.05
..... 1831	3.57	1.94	5.01	3.20	1.87	2.72	0.76	2.74	0.88	0.63	0.12
..... 1832	1.	1.41	4.43	3.06	1.82	2.34	0.48	2.72	0.55	0.14	0.10
Differ. in gen.	6.10	1.94	5.01	3.90	1.87	3.07	0.82	3.02	0.98	0.71	0.14

If we take into consideration the many known and unknown circumstances which may influence the temperature of the rock, we cannot be astonished that, in the foregoing table, the differences between maximum and minimum do not decrease in direct proportion to the depths, so that, notwithstanding the care with which the observations in the *Saxon Erzgebirge* were conducted, they still leave us in uncertainty respecting the depth to which the influence of the external temperature penetrates. Thus much, however, may be deduced from them, that, in certain circumstances, there is a yearly difference of temperature of scarcely 2° ($4^{\circ}.5$ Fahr.) at a depth of 17 feet; whilst under other circumstances, at twice that depth, a variation of 3° ($6^{\circ}.7$ Fahr.) may be produced. It is therefore hardly to be expected, that the depth to which the external temperature penetrates should be discovered, for any places in high latitudes, by observations in mines, wells, or caverns.

Finally, let it be observed, that the maximum in no case took place before August, and most commonly in September, October, and November; and the minimum never before February, generally in March, and in two cases as late as June. Herren-

schneider at *Strasbourg* also found, from thermometrical observations at a depth of 15 feet, that, in the years 1821 and 1822, the maximum took place in September, and the minimum in February; but in 1823, the maximum happened already in August, and the minimum in January. Muncke observed the maximum in a thermometer sunk five feet deep into the earth during the years 1821–1826, twice in September, twice in August, and once in July.*

Direct observations on the temperature of the soil have been made by sinking thermometers of different lengths into the ground, by Ferguson at *Abbotshall* in *Fife, Scotland*,† by Rudberg in *Stockholm*,‡ and by Quetelet at *Brussels*,§ the results of which are given in the following Table:

Depth below the Surface of Earth	STOCKHOLM, 59°20' N. Lat. In 1833 and 1834.			ABBOTSHALL, 55°10' N. Lat., 50 feet above level of the Sea, In 1816 and 1817.				BRUSSELS, 50°51' N. Lat., in a shaded situation, In 1834.			
	1 F.	2 F.	3 F.	1 F.	2 F.	3 F.	4 F.	0.5 F.	1.7	2.3 F.	3 F.
January .	29.28	31.29	32.74	34.71	37.51	40.64	44.01	45.3	45.7	43.33	47.42
February .	31.3	31.96	32.4	35.3	37.93	40.2	42.3	39.09	40.37	42.26	44.09
March .	32.59	33.1	33.39	37.22	38.53	40.71	42.34	43.04	43.47	44.49	45.57
April .	37.99	37.44	36.9	42.3	40.39	42.01	43.19	43.73	44.32	44.40	45.29
May .	47.94	46.76	45.14	45.31	46.49	43.99	44.09	55.76	55.2	53.54	52.64
June .	56.54	54.5	52.31	51.3	49.73	47.44	46.79	60.14	59.07	58.2	57.59
July .	60.5	59.0	56.9	54.61	53.63	53.32	48.6	63.64	62.79	62.92	62.1
August .	55.6	55.44	55.2	51.71	53.14	51.3	49.73	62.86	63.39	63.36	63.39
September .	53.89	53.52	53.39	52.22	52.1	52.1	50.31	58.79	59.89	60.6	61.24
October .	48.09	48.23	49.16	46.39	49.32	49.6	49.73	52.0	53.21	55.42	56.97
November .	38.92	40.3	42.19	40.81	44.21	44.54	46.6	44.14	46.59	48.8	51.19
December .	33.41	35.14	36.94	36.79	40.41	43.92	46.22	41.36	42.62	44.63	46.79
Mean .	43.79	43.8	43.9	44.09	45.22	47.79	46.2	51.01	51.5	52.19	52.92
Difference be- tween Max. and Min.	31.27	27.76	24.55	19.80	16.22	13.09	7.99	25.52	23.96	22.05	20.25

* Gehler's Neues Wörterbuch, vol. iii. p. 988.

† Ure's Chemical Dictionary. From the anomalous result of the July observation on the thermometer situated at a depth of three feet, of which no trace is to be found in any of the rest, it seems that either an error in the observation or a misprint must have crept in. For which reason Kämtz (*Lehrbuch der Meteorologie*, vol. ii. p. 183) adopted as the actual observation the number 8°.65, which he obtained from a formula derived by him from observation, and thus obtained for the greatest yearly difference of temperature 11°.99.

‡ Poggendorff's Annal. vol. xxxiii. p. 251.

§ Ibid. vol. xxxv. p. 139.

Thus we find that the maxima and minima take place at an earlier period than that given by the thermometrical observations made at greater depths in mines, which is in perfect accordance with the theory. We see further, that the differences between maximum and minimum decrease with the depth, and, indeed, much more rapidly than in the *Saxon* mines. This circumstance again proves that the temperature of the air has a considerable influence on observations in mines, and that a constant temperature would be found at a much lesser depth, if the thermometers could be constructed of much greater length than four feet, and the temperature of the earth be thus observed at a greater depth.

It is very remarkable that the observations made at *Abbots-hall* and *Brussels* should give such a considerable increase of mean temperature at depths differing but by a few feet. As the observations at *Stockholm* shew but a scarcely perceptible increase of temperature, and as they were made with the greatest care, it is highly probable that at the other places the observations were influenced by accidental circumstances.

CHAP. IX.—*Can it be maintained with certainty that the glaciers are melted from underneath by the internal heat of the earth, and what thermometrical phenomena accompany glaciers in general?*

The phenomena under consideration has already been pointed out by De Luc,* De Saussure,† and others, who have endeavoured to account for it by the continual radiation of the internal heat of the earth. Escher,‡ who observed the glaciers with great caution, considers this melting of the glaciers from underneath as an undeniable fact. He says, “They would soon reach the highest limits of the mountains between which they are contained, were they not melted away from underneath by the internal heat of the earth, so as to cause the underminings and fallings in, by which an equilibrium is constantly maintained in the mass of the glaciers, between the accumulations at the surface and the loss sustained from underneath. It is by this

* Rech. sur l'Atmosph. ii. 327.

† Voyages dans les Alpes, § 533.

‡ Gilbert's Annalen, lxi. p. 113.

means alone that springs are enabled to take their rise under the glaciers, and to flow uninterruptedly throughout the winter. Only in such places where these high glacier-bearing longitudinal valleys of the Alps are intersected by cross valleys, or where high glacier-bearing mountains stretch down into deep valleys, will the towering glacier masses be forced down the steep declivities, and urged forwards by their own weight into the valleys situated below the limits of perennial snow, where they will continue uninterruptedly to melt away from underneath, whilst their upper surface will only be melted during the warmer seasons."

The melting of the glaciers from underneath can only take place where the mean temperature of the soil is above 32° . For at such elevations, where it is equal to or below 32° , and where the glacier prevents the access of the warm summer air to the soil, it will no longer be possible for the ice to be melted on its under surface. Let us suppose an alpine valley, the mean temperature of which is 32° , to be covered with a glacier at a time when the temperature at the surface is also 32° , and that the masses of snow have the same temperature, the snow will then neither receive heat from, nor give heat to, the soil beneath. If the temperature of the soil be above 32° , this excess of temperature will be expended in melting a part of the snow, until the equilibrium be restored; in the contrary case, the soil will receive heat from the snow. The law of the decrease of temperature from the centre of the earth to its surface is, therefore, not permanently deranged by a covering of snow, where the mean temperature of the soil is 32° , and it is consequently impossible to conceive, that a greater quantity of heat should at any time be emitted from the interior, by which the snow should be melted. The covering of snow will produce no other effect, except that the variations of the temperature of the soil, occasioned by the variations of the seasons, will be confined within very narrow limits, or if the covering of snow be very thick, that they will entirely disappear. However, as the temperature of the surface is only the consequence of the cooling of the earth, caused by the radiation of heat from its surface, which cooling is not compensated in all climates by the radiation from the sun, it is possible that, beneath a glacier where no radiation

can take place, the original temperature of the soil may be somewhat raised. At such elevations, therefore, where the mean temperature of the soil is 32° , glaciers can only be melted on their upper surface, and during the warmer seasons, but in the winter no water can possibly flow from them.

If the mean temperature of the soil in the Alps, at an elevation of 6165 feet, is 32° F. (see Chap. XVIII), glaciers which lie at that height can no longer be melted away from underneath.* It would be very interesting, for the further investigation of this question, to ascertain the height in various parts of the Alps, at which the mean temperature of the soil is zero.

The lower extremity of the great *Lammern* glacier, on the *Gemmi*, in *Switzerland*, is situated about 7000 feet above the surface of the sea.† The mean temperature of the soil at that place must, therefore, be about $34^{\circ}.47$. On the 5th September 1835, at a few hundred feet from the glacier, and eight feet from the bed of the brook, which at that time was dry, I found the temperature of the soil at one foot from the surface to be $41^{\circ}.9$; whilst at the highest point of the *Pass of the Gemmi*, which has about the same elevation above the sea, it was only $38^{\circ}.5$. The former of these must, therefore, have been $44^{\circ}.57$, and the latter $41^{\circ}.27$ above the mean, a result which nearly accords with the observations made at the depth of one foot, communicated in Chap. VIII. But I also observed the temperature of fifty-one fresh-water springs on the *Spital Matte*, 5887 feet above the sea on the 3d September, and found the coldest of them to be $37^{\circ}.8$, and as, according to my observations on the temperature of the springs of the mountains in the vicinity of my residence (see Chap. XVIII), this temperature must have been

* Hugi (see Berghaus Annal. iii. 290), has given the height above the sea of the lower extremities of twelve glaciers in *Switzerland*. Among these the *Oberaar* glacier (7980 feet above the level of the sea) is the only one which would not melt away from underneath; all the rest are so situated as to reach below the limit of 6165 feet, and consequently into regions where the mean temperature is above $32^{\circ}.0$.

† I found by my barometrical measurement, made between 200 and 300 feet above its lower extremity, that its height was 7244 feet above the level of the sea.

about $33^{\circ}.01$ above the mean, the mean temperature of that spring must have been about $36^{\circ}.81$.

However, as these springs rise out of the limestone rocks, which are there so enormously fissured, and therefore probably rise from a great depth, it is to be supposed that they are thermal, and that the coldest of them bears a higher temperature than the mean temperature of the place where it rises. If this is the case, it is very possible that the mean temperature of the soil on the *Spital Matte* does not exceed $32^{\circ}.92$, as was supposed in Chap. XVIII.

Now, if the mean temperature of the soil near the *Lammern* glacier is below 32° , it must be one of those glaciers which cannot melt from underneath.

I was enabled to assure myself of the correctness of this opinion in another manner. The brook which flows from this great and broad glacier was on the 5th September so small, that one might easily walk through it. Besides, even that small quantity of water seems for the most part to have proceeded from a waterfall, which precipitates itself into the glacier on the north side, and reappears at the lower extremity; for during my stay there the temperature of the air was only $38^{\circ}.7$, so that but very little could have melted away even from the upper surface. The water which trickled down from the surface of the glacier was also very inconsiderable.

I learned from my guide, a well-informed chamois hunter from the *Baths of Leuck*, that the water of this glacier-stream decreases as the seasons advance, and that in winter no more water flows out of the glacier. The same is the case with two small brooks, which fall in cascades from a small glacier, stretching down from the *Daubenhorn*. There can be no doubt that these also only result from the melting of the ice on the upper surface of the glacier by the heat of the atmosphere.

My guide also related to me some remarkable facts concerning the ice-cold, periodical spring of the *Leibfraw*, mentioned by Ebel,* situated 200 paces distant from the *Baths of Leuck*, which are also corroborative of the above opinions; namely,

* Anleitung die Schweiz zu bereisen Zürich, 1810. 3d edition. Part iii. p. 333.

when in the spring, water falls from the *Lötsch glacier* over a certain rock, which he pointed out to me, three days afterwards it flows out at that periodical spring, which has five outlets, all situated very near together, and, indeed, in such abundance that it might be used for driving a mill. This usually takes place in June; however, it depends upon the earlier or later commencement of the summer. These springs are also more copious the warmer the summer is. When the water ceases flowing over the rocks, the springs also, after three days, disappear, and this usually happens at the end of August, or the beginning of September. During my stay at *Leuckerbad*, the 3d and 4th of September, the spring only flowed from one of its onlets, and I learned from an engineer of the place, that the others had only ceased flowing a few days before. And, on the 5th, I observed no more water running over the rock. I have the less reason to doubt the information of my guide, as the low temperature of the spring ($41^{\circ}.4$) can only be accounted for by supposing it to come either from a great height or out of a glacier. In the latter case, it can only proceed from the melting of the ice from the upper surface of the glacier during the summer. According to Hugi the lower extremity of the *Lötsch glacier* lies 5802 feet above the level of the sea, and consequently, according to Chap. XVIII., at an elevation where the mean temperature of the soil is $32^{\circ}.0$.

It may therefore be assumed, that the glaciers in the *Alps*, which lie more than 6165 feet above the sea, are no longer melted away from underneath, by the internal heat of the earth; but that they are melted only on the upper surface by the heat of summer, and by rains.* Thus, on the upper surface, a layer of ice, although, *perhaps*, a somewhat thin one, will be formed, under which there will be nothing but soft snow to an unknown depth.† The thickness of this covering of ice will, of course, depend on the depth to which the water, resulting from the melting of the snow during the day, sinks and freezes during the night.

* On the heights up to which the yearly fall of snow is melted away again, see Escher, p. 123.

† Von Buch in Gilbert's *Annal.*, vol. xli. 15. De Saussure, *Voyages*, ii. 214, § 530.

If we trace a glacier from its lower to its upper end, we find that the crystals of ice become continually harder, till, at a certain height, it consists of nothing but a loose granular mass of snow, which, in *Switzerland*, is called *Firn*.* The height at which this *Firn* first appears, and which Hugi proposed to call the *Firn-line* (*Firmlinie*) is, according to his observations in the *Alps*, a fixed line, which undergoes neither elevation nor depression, whether on a northern or southern declivity, or from any other cause. He found the *Firn-line*, from observations on a great number of glaciers, to lie between 7614 and 7698 feet above the level of the sea. In the *Pennine Alps*, the *Firn-line* seems to lie somewhat higher, at least the observations on the *Gries*, and on the ridges of the *Binnenthal*, give it at near 7800 feet. Glaciers properly so called do not reach this *Firn-line*; for, at the height of 7600 feet, where the mean temperature, according to Chap. XVIII., is about $36^{\circ}.5$, the glaciers of the *Alps* are quickly converted into *Firn*.†

All these circumstances may be satisfactorily explained, if we consider that, where the mean temperature of the soil becomes $32^{\circ}.0$, the glacier no longer melts away from underneath, but only on its upper surface, during the summer. The greater number of the glaciers in the *Alps* extend far below the limit of 6165 feet, and consequently rest upon a soil, the mean temperature of which, if not covered with ice and snow, would be above 32° . It is this excess of heat above 32° which may possibly be employed in promoting a continual melting of the glaciers from underneath. Theoretical considerations bring us to the following conclusions:—The covering of an alpine valley with a glacier, causes a disturbance in the original law of the progressive decrease of heat from the centre of the earth towards the surface, which cannot be repaired so long as the covering remains; but the law is not entirely destroyed. A distinction must therefore be made between the actual temperature

* Hugi in Berghaus Annal, iii., 295, Some of the assertions of this diligent explorer of the Alps, may perhaps be found to require some corrections, when subjected to a closer investigation. It certainly is not true that the masses which are converted into glacier ice lie deeper the higher the glacier lies above the *Firn*. I. 1. p. 294.

† I. 1. P. 289.

of the soil beneath the glacier, and that which it would otherwise have, considering only its latitude and elevation above the sea. The difference between these two is the expression in degrees of the thermometer, for the quantities of heat communicated from the earth to the glacier lying upon it. The quantity of ice melted from the under surface of a glacier, in a certain time, would give an exact measure for the quantity of heat radiated from the earth. But we have no means of ascertaining that quantity with any degree of certainty. It is well known that stones, wood, corpses, &c. which fall into holes and fissures in the ice, but do not reach the bottom of the glacier, are again brought to the surface by the melting of the ice on its surface.*

In the year 1828, Hugi buried several stones from ten to twelve feet deep in a glacier, and covered them in with ice, and the following year they were all on the surface again. This would give a measure for the quantity of ice melted away from the upper surface, and the absolute sinking of the stones would yield a measure for the melting of its under surface, did not the movement of the glaciers (the openings of the fissures), &c. occasion frequent changes in the position of the stones,† and if the angle which the under surface of the glaciers makes with the horizon were not unknown.‡

* The common people in the *Alps* say, that the glacier will not suffer any foreign matter to remain in its interior. And, in fact, I have in vain endeavoured to discover even a single stone in the exposed masses of ice at the extremity of the glaciers. This is very plainly exemplified at the upper *Grindelwald* glacier, where perpendicular walls of ice, of more than 100 feet in height, are exposed to view. See Bissels, in Gilbert's *Annal.*, vol. ixiv. p. 198. However, at the lower *Grindelwald* glacier, the walls of ice are seen to be traversed by stripes, coloured brownish by earth.

† Kämtz, in Schweigger—Seidel's *Journal*, vii. p. 261.

‡ From Mr Stählin's daily observations of the height of the *Rhine* at *Basel*, continued from 1809 to 1820, Escher calculates (*Gilb. Annal.*, lxx. 202) that the *Rhine* carries off one billion and 46,000 million cubic feet of water yearly out of *Switzerland*. Now, supposing only one-half of this quantity to proceed immediately from the glaciers, and that of the fifty square German miles, which are said by Ebel (*Part iii.* p. 121) to be occupied by the glaciers of the *Alps* between *Mont Blanc* and the frontiers of *Tyrol*, only twenty square miles are tributary to the *Rhine*; then, if the specific gravity of the water be considered equal to that of the ice of the glaciers, we find that, on an average, a mass of ice of fifty feet in thickness is melted away yearly from

Although it was to be expected *a priori* that the temperature of the soil under glaciers, however low they might extend, would never be much above $32^{\circ}.0$, yet I was desirous of satisfying myself on this point by direct observations.

Very near the lower extremity of the lower glacier of *Grindelwald*, on the 25th August 1835, I bored a hole six inches deep into the ground, and placed a thermometer in it. It marked $36^{\circ}.5$. At the upper glacier I found a temperature of $39^{\circ}.8$ twelve inches deep in the ground, as near to the ice as possible, but separated from it by the glacier stream, called the *Black Lutschine*. That neither of these temperatures was as low as $32^{\circ}.0$ is not to be wondered at; for, although they were observed as near as possible to the ice, yet these points were exposed to the air, which, at the lower glacier, had a temperature of $39^{\circ}.8$, and at the upper $45^{\circ}.5$. How trifling the distance is to which the coldness of the ice and the water issuing from the glaciers is felt, is proved by the latter of these experiments. The hole was bored so near the bank of the *Lutschine*, that its waters, of $33^{\circ}.3$, almost washed over the thermometer, yet did not quite communicate with the hole; and, notwithstanding this small distance, there was a difference between them of $6^{\circ}.53$. In like manner I found a difference of $8^{\circ}.90$ between the temperature of the earth and that of the stream, immediately on the bank of the (*Schwarze Lutschine*) *Black Lutschen*, near the bridge, between *Grindelwald* and the lower glacier, and at a distance of only eight paces, the difference was $14^{\circ}.40$. There can, therefore, be no doubt, that an observation made directly under the ice, would give a temperature very near $32^{\circ}.0$. I say very near zero, for the temperature of the soil under glaciers is seldom exactly 32° , since the streams that issue from glaciers, at the very moment of their exit, invariably shew a temperature a little above 32° . For example, six observations on the streams which issue from the lower glacier, at *Grindelwald*, all gave me a tem-

those glaciers. Those natural philosophers who reside in the *Alps*, and are able to make their estimates more exactly, may easily make the necessary corrections in this calculation.

* Even if the stony nature of the soil under the glacier had allowed of such an experiment, the result would have been equally undecisive, as it would hardly have been possible to prevent the infiltration of water into the hole.

perature of $32^{\circ}.9$, another very small stream shewed $32^{\circ}.7$. The brook which flows from the upper glacier, gave a temperature of $33^{\circ}.3$, and that of the *Lammern* $32^{\circ}.4$. As my thermometers shewed exactly $32^{\circ}.0$ upon being plunged into a hole in the melting glacier, it is certain that they were correctly graduated.

There are three causes to which this elevation of temperature may be ascribed; firstly, the warm air drawing into the ice-caverns from which these glacier-streams issue, may tend to raise the temperature of their waters. This may be the case especially in the lower *Grindelwald* glacier; in a less degree in the upper *Grindelwald* and *Lammern* glaciers, because in neither of them does the water issue from caverns in the ice, but flows immediately from under the ice; secondly, the heat of the earth may assist in warming them; and thirdly, springs and streams of water, coming down from the mountains between which the glacier is enclosed, and flowing underneath the glacier, may also assist in raising their temperature. This seems indeed to be the case with the upper *Grindelwald* glacier, and may account for the high temperature of $33^{\circ}.3$ of the *Schwartze Lutschine*; namely, from the *Wetterhorn* there descends a considerable brook, the *Weisbach*—and from the *Mettenberg* a still larger one, called the *Milchbach*, both of which penetrate into the glacier, the one on the east, the other on the western side. Although these streams are nothing else than glacier-streams, proceeding from the upper parts of the glacier, yet during their course above ground they will acquire, in the warm seasons, a higher temperature, which they will afterwards communicate to the other waters with which they unite beneath the glacier. That there are currents of air between the descending stream of water and the ice, notwithstanding that there is no cavern in this glacier, is proved by the well-known adventure of the inn-keeper of *Grindelwald*, *Christian Boren*, who fell into a crack 354 feet deep in this glacier, crawled up 396 paces on his belly in the bed of the *Weisbach*, which he was three and a half hours in accomplishing, and came out on the *Wetterhorn*, where the *Weisbach* enters the glacier, having sustained no further injury than a broken arm. His son told me that his coat buttons were all rubbed off except the two top ones.

The canal was therefore very narrow; but yet, of course, filled with air.

That the above causes tend in most cases to raise the temperature of the waters which issue from them, is also proved by the observations made at my request by my friend Professor Ennemoser in *Tyrol*, in the summer of 1833. At ten different parts of six glaciers, he found the temperature of the water to rise as high as $34^{\circ}.2$. The large brook, which issues from the *Pfelderer* glacier, shewed at its first appearance a temperature of $35^{\circ}.8$. This high temperature was probably caused by this glacier having a southern aspect, and by the cavern out of which the stream flows extending itself very far beneath the glacier; for Ennemoser succeeded in penetrating to a great distance into the cavern, along the bed of the brook, and saw that the cavern extended much farther. And as the observation was made in July, there is the more reason to believe that this stream was indebted for its high temperature to warm currents of air.

The waters which collect on the glaciers themselves, as well as those which lie stagnant in holes in the ice, I found from numerous observations in the *Eismeer* of the lower *Grindelwald* glacier, and on the *Lammern* glacier, to have a temperature always between $-32^{\circ}.2$ and $32^{\circ}.0$. Into one of these holes, which was $8\frac{1}{2}$ feet deep, with almost perpendicular walls, and the opening of which measured $2\frac{1}{2}$ square feet, I sunk a glass bottle, which had been previously filled with water, of the surface of the hole, nearly to the bottom. I enveloped the bottle in wood-shavings, in order to prevent the contact of the glass with the ice. After the bottle had remained there 65 minutes, I drew it quickly up, and found the temperature of the water to be $+32^{\circ}.4$. At the surface, the temperature in this hole had a temperature of exactly $32^{\circ}.0$, while some which ran slowly into it out of a crack, about one inch deep, gave a temperature of $-32^{\circ}.2$. The water which had collected in another hole, six feet deep, showed a temperature of $+32^{\circ}.4$ already at its surface. These observations prove clearly, that water which lies stagnant in holes in the ice, is warmed at its surface by the contact with the air, and, being thus rendered heavier, sinks to the bottom. It is well known that Rumford* has endeavoured to account for the formation of these holes in the glaciers, as well as

* Gilbert's Annals, lxviii. 362.

their becoming deeper during the warm seasons, by the sinking of the particles of water, which have been warmed by the warm air at the surface, into the ice, by which the ice is melted away in a perpendicular direction. The holes seem, however, to owe their first existence, as Ebel* observes, to stones, which become heated by the sun to a greater degree than the surrounding ice, melt away the ice around them, and thus penetrate into the glacier. And, in fact, whenever I have been able to see to the bottom of such holes, I have invariably discovered one large or several small stones. It is evident that these stones can only continue to sink deeper into the ice, so long as the summer lasts, for after the water in them has become frozen during the following winter, the conditions necessary for the further sinking of the stones in the ensuing summer can no longer exist. On the contrary, the melting of the ice from the surface, gradually brings the stones out again. This sinking and reappearing of the stones may be continually repeated, until they reach the lower extremity of the glacier, or are precipitated into clefts, which extend to the bottom of the glacier. In this manner the stones may, by the sliding of the glacier, be made to perform a journey *en échelons*.†

As these holes in the ice never reach the bottom of the glacier, and as the water which falls into the clefts is never above 32° , it is not possible that the water, which filters down from the surface to the bottom of the glacier, should come there with a temperature higher than 32.0 , which they have when they issue in streams from the lower end of the glacier. We are,

* *Loco citato*, part iii. p. 117.

† This seems to me to account very plainly for another phenomenon, namely, since the glacier consists of a mass of snow irregularly intermixed with frozen water, and is consequently granular opaque, and very different from ice formed by the freezing of stagnant water, we ought to be able to distinguish that ice which was formed by the freezing of the water in holes in the glacier, from the rest of the mass of the glacier. But Escher remarks, that not one of the philosophers who have explored the Alps has been able to make such a distinction. (See Gilbert's Annals, lxix. 118). It is, however, evident, that it must be equally impossible to find any of the ice formed in the clefts of the glaciers, at the lower extremity, as to find the stones, because, when these reappeared at the surface, the ice by which they had been covered must necessarily have been melted away.

therefore, obliged to have recourse to the above mentioned sources of heat, in order to account for this high temperature.

But if, as was to have been expected, *a priori*, the temperature of the water precipitated into the clefts of the glacier, is $32^{\circ}.0$, and if, as our experiments seem to shew, the highest temperature which it assumes before its exit at their lower extremity, is $35^{\circ}.9$, then can the temperature of the soil beneath the glaciers nowhere be much higher than $32^{\circ}.0$. This only refers to the warmer seasons; but as beneath the glaciers the earth is protected from the cooling effects of radiation, as even a very considerable degree of cold in the atmosphere is not capable of penetrating through a mass of ice of several hundred feet in thickness, and as, during the winter, the cold is almost, or perhaps entirely, prevented from penetrating into the caverns in the ice, by their being choked up with snow and ice, the temperature of the soil under the glacier will, even in winter, hardly be reduced below 32° . The yearly mean temperature of the soil under glaciers is, therefore, without doubt 32° .

The lower extremity of the lower *Grindelwald* glacier, lies, according to my barometrical measurement, at an elevation of 2989 feet above the surface of the sea, in a region where the mean temperature of the soil is much above $32^{\circ}.0$. Up to the *Eismeer*, at the foot of the *Vischhörner*, the glacier rises to a height of 2140 feet. So that even the *Eismeer*, at a height of 5129 feet above the level of the sea, lies in a region where the mean temperature of the soil is above $32^{\circ}.0$. Up to this limit, then, the glacier may be melted away from underneath, but not above this.

In *Grindelwald*, 248 feet above the lower extremity of this glacier, I found the temperature of the soil one foot below the surface, on the 26th August, to be $56^{\circ}.7$; on the *Metterberg*, near the *Eismeer*, and on the same level with it, it was $45^{\circ}.5$. At the former place the mean temperature will, therefore, not be much above $43^{\circ}.2$, at the latter hardly $36^{\circ}.5$.

Glaciers may be indirectly melted away from underneath at the expense of the internal heat of the earth, when, in the higher regions of the glacier water descends through cracks and fissures deep into the earth, and, having there acquired a higher temperature, reappears beneath the glacier at a lower point. This

will more especially take place when the glacier rests, as most of those in the high lands of *Bern* do, on very fractured limestone rocks, in which we so frequently see rivulets disappear in the upper regions and shew themselves again lower down. I have witnessed many examples of this in the valley of the *Lutschine* between *Interlaken* and *Grindelwald*, on the *Spital-Matte*, and on the *Gemmi*. With a little attention many more such examples might be discovered. Directly on the north side of the heap of debris, (*Gandecke*) of 77 feet high, near the upper *Grindelwald* glacier, close to the *Bergelbach*, I found four springs whose temperatures were from $37^{\circ}.4$ to $38^{\circ}.2$, and which, as they are situated 40 feet below the lower end of the glacier, certainly owe their existence to water melted from the glacier, which flows down through clefts and underneath the glacier, from the higher regions. The low temperature of these springs, together with the appearance of one on the heap of detritus itself, having a temperature of $47^{\circ}.4$, and which could, therefore, not proceed from the glacier, are a sufficient proof of this. In former times, according to *Ebel*,* in the year 1720, when the glaciers probably also covered these springs, the case now under consideration must have taken place.

In like manner, but in a higher degree, the melting of the glaciers from underneath, by means of the springs which descend from the lateral mountains, will take place, as we have before said, when they rest upon a rock, which is almost or entirely free from fissures. On the road from *Grindelwald* to the *Eismeer*, on the eastern declivity of the *Mettenberg*, I found more than 14 springs and brooks, which altogether carried off a very considerable body of water. Their temperatures varied between $42^{\circ}.01$ and $49^{\circ}.3$, and their mean was $45^{\circ}.83$. It is true that several of these waters only proceeded from the rain and snow, which had fallen during the last few days, and that only a few of them fell under the glacier; but there were several others, of which even the oldest came down under the glacier, between the ice and the side of the mountain, with a temperature of $42^{\circ}.01$. It cannot be doubted that, even in winter, the springs which rise in this space must flow under the glacier.

* III. p. 173.

As water of 41° , according to Rumford's* experiments, when left for 30 minutes in contact with ice of 32° , melts away about $\frac{1}{25}$ of its own weight from the ice, and becomes 3° colder, it will melt about one-eighth of its weight by the time that it reaches 32° . This will give an approximate measure of the increase of a spring, of the above temperature, which flows under a glacier.

The springs at *Leuckebad*,† which rise in such enormous quantities, and with a temperature between $115^{\circ}.2$ and $124^{\circ}.0$ at a height of 4295 feet above the level of the sea, render it very probable that hot springs may also come up under glaciers.‡

* Gilbert's Annal. vol. i. p. 334.

† Besides the *large* or *Lorense* spring, which rises like a brook in the front of the Bath-house, and is the warmest, I found twelve others at a little distance from the village, on the north-east side, which are all unused except two, and run into the *Dala*.

‡ Many a warm spring may perhaps lie concealed in the deep valleys of the Alps. And as, in general, such springs rise according to the laws of hydrostatics, at the lowest part of the valley, we must expect to meet with them in the bed of the glacier streams. But there they can only be seen during the winter. Thus, in the winter of 1831, some fishermen for the first time discovered a warm spring of 113° in the bed of the *Rhone*, near the village of *Lavey*, to the south-east of *Bex*, which the government of the canton *Waadt* caused to be enclosed, and which has been raised since then to a watering-place. (See *Ann. de Chim. et de Phys.* vol. lviii. p. 109, and *Journ. für Pract. Chemie*, vol. ii. p. 82.) The fissures certainly descend to a great depth in some places into the interior of the rocks. This is evident from the water which oozes out at the foot of the high and naked cliffs of limestone. A most striking example of this is presented by the mountain over which the wonderful pass of the *Gemmi* leads, and which rises perpendicularly to the height of about 2000 feet. From all points of this cliff, from top to bottom, drops of water are seen to exude, and for the most part to unite below into a small brook. As when I crossed this pass, it had not rained during the last five days, this water must have come out of the interior of the rock. This is also very strongly corroborated, by the fact that the *Daubinsee* on the *Gemmi*, which measures one-half a league in length, has no visible outlet, although it receives the water which comes from the great *Lammerr* glacier, as well as all the rain and snow which falls upon the surrounding high mountains; further, that several small streams which come from the *Daubenhorn* gradually lose themselves in the earth; and, lastly, that on the *Gemmi* (as in the limestone rocks of *Crain*, especially near *Triste* and *Fiume*; see *Gilb. Ann.* vol. xlv. p. 408, and on the *Wurtemberg Alp*, see *Kastner's Archiv.* v. 34) are found funnel-shaped holes, into which the rain-waters disappear. But waters thus sinking here and in other places through high mountains into the interior, will become heated, and will return to the surface in the valleys as warm springs. Examples of

The lower extremities of the two *Grindelwald* glaciers lie respectively 1306 and 571 feet lower than *Leuckerbach*. But warm springs may be met with at a still greater height than *Leuckerbach*. (See Chap. XVII.)

If we suppose the melting of the glaciers from underneath to be a consequence of the internal heat of the earth, we must also imagine it to be totally independent of the seasons, and that it takes place in winter as well as in summer. Saussure,* Escher,† Ebel,‡ and others, inform us that the glacier streams flow also in winter; however, the latter observes that they are less copious in that season.

Although the testimony of such philosophers as these, resident in the Alps, and gifted with such talent for observation, would be sufficient, yet I endeavoured during my stay in the Alps to obtain information myself upon this subject. All the inhabitants of *Grindelwald*, of whom I made my inquiries, agreed in assuring me that the lower glacier does not yield a single drop of water in the winter, but that the *upper one* continues to flow uninterruptedly. Supposing this information to be correct, I thought this difference might be explained by supposing that, as the brook which issues from the upper glacier has a temperature 4°.50 higher than that of the lower, its flowing uninterruptedly might be due to springs rising beneath the glacier. The chamois hunter I before mentioned, told me that the *Dala*, near *Leuckerbach*, which springs out of a glacier hanging down from *Balmhorn*, and also the *Massa*, which issues from the great *Aletsch*, a glacier extending from 9 to 11 leagues down from the south side of the *Jungfrau*, and terminating within two leagues of the *Rhone*, flow throughout the winter. But the upper *Lotsch* glacier, as I have already observed, does not yield a drop of water during the winter. In like manner, Ennemoser was informed that the *Pfelderer* glacier in *Tyrol* runs in winter as well as in summer.

fissures extending to a great depth, and which are particularly frequent in the limestones, are to be found in the *Jura*, as for instance is proved by the *Orbe* spring, which is nothing else than the outlet of the lakes in the valley of *Joux*, which lie 680 feet above it.—*Voyages dans les Alpes*, vol. i. p. 309. Ebel, part iii. p. 221 and 586.

* *Voyages*, i. 453.

† *Gilb. Annal.* vol. lxix. p. 123.

‡ *Ibid.* iii. 121.

The scientific zeal of Mr Ziegler, the pastor of *Grindelwald*, and the observations so readily undertaken by him, and to which we shall return in Chap. XVIII. have enabled me to add to the above something more satisfactory. To his observations on the temperature of the soil, made at the depth of four feet near the lower glacier of *Grindelwald*, Mr Ziegler added observations on the melting of the glacier itself during the last winter. The former will not render us any assistance until next September, when the yearly series will be finished, but the latter has already yielded some very valuable results.

Temperature of the Soil.

1835,

Sept. 23. 39°.1.

Oct. 27. 35°.8. The temperature of the air inside the ice-grotto, close to the ice was 37°.8. The glacier melted away almost imperceptibly. The water which issued from the cavern was perfectly clear.

Dec. 2. 33°.3. South-west wind (called in *Switzerland* Föhn); the temperature of the air close to the glacier was 45°.5; the glacier melted away.

Dec. 28. 32°.7. The temperature of the *Schwarze Lutschine* under the ice, near the *Mettenberg* Bridge, was 32°.2. The severe cold, which continued through the whole of December, began on the 6th. From this time no more melting of the glacier could be perceived; indeed the water, which, on the 2d December, and perhaps for a few days afterwards, was clear and of a greenish colour, and which probably proceeded, as is the general opinion of the inhabitants of the place, from the brooks and springs, which throw themselves into the glacier above, was frozen to the bottom. This was observed, not only in a hole under the ice, which the inhabitants of a neighbouring cottage had made in the first covering of ice for the sake of obtaining water, but also in the ice-grotto itself, where Mr Ziegler had the ice broken up with a pick-axe, in order to ascertain the fact.

1836,

March 1. 32°.2. About the middle of February a rapid thaw took place, which lasted several days, and some persons assured Mr Ziegler that water ran from the glacier during that time; but it soon froze again to the bottom, and on the 1st March not a trace of water was to be seen.

April 4. 33°.1. Still no water made its appearance; and even on the 14th of April, the covering of ice and snow over the glacier stream was not broken, although there were frequent thaws throughout the month of March, and in the first half of April there fell a great deal of rain mixed with snow. Mr Ziegler, however, suspected that the water would soon burst violently forth, and overflow its customary channel.

These observations of Mr Ziegler's corroborate the information obtained from the inhabitants of *Grindelwald*. They prove

that, in the winter, no more ice is melted away from the lower end of the glacier. And this was no more than was to be expected, as the freezing temperature to which the soil beneath the lower end of the glacier is exposed in winter, must necessarily cool it down to the freezing point, or still lower. These observations also prove, that even at the depth of four feet, the earth was reduced to the freezing point, so that at a less depth the temperature must certainly have been below 32° . But from this it by no means follows, that the temperature of the soil under the glacier, at a distance from its lower extremity, where it is not exposed to the immediate influence of the frost, is reduced to so low a degree. We must, therefore, still allow of the possibility of the melting away of the glacier from underneath, at the expense of the internal heat of the earth in those places. In this case, however, the water cannot effect its escape from under the glacier, because so soon as it approaches the lower extremity, it must freeze, and form such a dam of ice as to prevent all possibility of escape.

If it is as certain that some glaciers yield water in the winter, as that others give none, there seems scarcely any other mode of accounting for this difference, than by supposing the melting of the under surface of the glacier in the latter case only to be effected at the expense of the internal heat of the earth, and in the former by the additional assistance of springs, by means of which the water, even during the winter, acquires a temperature higher, though perhaps but by a few tenths of a degree, than the freezing point, which renders the uninterrupted efflux possible.

But where do the waters remain which in winter cease to flow from under the glaciers? Ebel* relates, that, in winter, nothing is to be seen of the caverns in the ice at the lower end of the glaciers: they are covered with snow and ice, but in the spring and summer the swollen streams break through the ice, and form caverns of 100 feet in height, and from 50 to 80 feet broad, the shape and size of which are variable.

This swelling of the water might, indeed, be attributed to the

* Part iii. p. 120.

spring rains, which re-open the fissures in the ice, which had been stopped up with snow during the winter, and carry down great quantities of water, which burst a passage through the choked caverns. But if the caverns should be thus burst open before the fissures had been cleared out by the rains, the passage could only have been forced by the water which had collected under the glacier during the winter.* But as in glaciers which rise to a considerable height, the lower extremity lies in a much warmer region than the clefts into which the waters are precipitated, it might be expected that the caverns would be *reopened* sooner than the clefts in the glacier. It is not beyond the power of human observation, in the spring, to ascertain the real fact concerning this phenomenon. Well informed chamois hunters, who ascend the glaciers at almost all seasons, would be the most proper persons to undertake such observations.

There is another method, which, if pursued with caution, would give some information respecting the melting of the glaciers from underneath,—namely, if we suppose the glacier streams only to proceed from three sources; first, from springs and streams which sink into the glacier in higher regions; secondly, from the melting of the ice during the summer months on the upper surface of the glaciers; and, thirdly, from the ice melted away from the under surface of the glaciers, their contents of fixed substances must be different in the different seasons. The quantity of fixed substances contained in the streams which fall in the course of a year into the glaciers, as well as in the springs which rise underneath them during the same period, may be considered as constant. The water resulting from the melting of the glaciers on their upper surface during the warm season, can contain scarcely a trace of fixed substances, and that only when the glacier is covered with heaps of rubbish (*gufferlinien*). However, as these waters are precipitated into the fissures in the ice, and thus unite beneath the glacier with those of the streams and springs, they are enabled to take up fixed

* Subterranean accumulations of water actually exist in the winter according to Ebel (part ii. p. 96), between the *Valsoré* glacier and the perpendicular wall of *Mont noir*, for a hole in that neighbourhood (called the *Gouille à Vassu*) 104 feet deep, remains from the autumn till July full of water, which in July breaks through under the *Valsoré* glacier, and forms ice caverns.

particles from the rocks over which they pass. But it is hardly to be expected that they would dissolve any other substances than carbonate of lime, if the rocks contain that substance; for we cannot suspect the presence of any more soluble salts in the rocks, because if they had ever existed, they would have been washed away already long since. The quantity of carbonate of lime which they dissolve, must also be very inconsiderable, as they have no opportunity of absorbing carbonic acid, while the atmospheric waters which supply the springs are already partly impregnated with this acid, and are also supplied with it from the superficial soil through which they pass. The same train of reasoning is of course also applicable to the water melted from the under surface, whether at the expense of the internal heat of the earth, or by the heat of springs and streams of water; but with this difference, that in this water we may suspect the total absence of carbonic acid, and consequently the least possible power of dissolving the lime. So that the more melted ice is mixed with the streams and springs under the glacier, the more will their original contents of fixed substances, and especially of very soluble salts, be diminished; and thus we may expect to find the smallest proportion of fixed substances in the streams which issue from under the glaciers, in summer, and the greatest proportion in the season when the melting of the glaciers almost or entirely ceases. From this we see that, by analyzing the water of the glacier-streams at various seasons, we may gain results, from which the quantity of ice melted away from the glacier may be inferred. If, for example, an analysis were made at the time when the temperature of the atmosphere is brought down just below 32° , the water could not possibly be mixed with any but that melted from the under surface of the glacier. If at the same time several neighbouring springs were also analyzed, and if the weakest among them still contained a greater proportion of fixed parts than was found in the glacier-stream, it might be concluded, with great probability, that the glacier still continued to be melted away on its under surface. In those glacier streams which flow throughout the winter, as, for example, that which issues from the upper *Grindelwald* glacier, the analyses might be continued in the severest frosty weather, and if it should be found always to con-

tain less fixed parts than the neighbouring springs, it would be a proof that the glacier still continued to melt away from underneath ; while on the other hand, if the quantity of fixed substances should be found to increase till it became equal to that in the springs, it might be inferred that the melting of the glacier had ceased.

I confess that the conclusions, drawn from the results of such experiments, would only be within the range of probability. But what is left but probability in a field where absolute certainty is hardly possible to be attained ?

An excellent spot for making these experiments would be *Grindelwald*, where in the winter one glacier, the upper one, always yields water, while the other, the lower one, gives none.

Mr Pagenstecher, the apothecary at *Bern*, had the goodness last autumn, at my request, to subject the water of the *Lutschine*, which issues from the lower glacier of *Grindelwald*, to a chemical examination, and communicated to me the following :

This water was taken from the cavern on a fine clear day near the end of October 1835, under the inspection and direction of Mr Zeigler, who sent it to Mr Pagenstecher with the following remarks. " At the time the water was taken, I ascertained that the glacier did not melt in the least. Last Sunday, when I also visited the glacier, it already melted but very inconsiderably, although the wind was from the south-west. On the bottom of the cavern wherever the rays of the sun did not penetrate, at this season the sun did shine on the lower end of this glacier only for one and a half hours during the day, I saw small icicles similar to those which are formed on the roofs of houses. It is, therefore, highly probable that the clear transparent water which now issues from the glacier proceeds only from springs ; at least I cannot imagine how it could possibly be supposed to result even in part from the melting of the ice." When the water arrived at *Bern* it was also clear and colourless, and no trace of sediment would be perceived in the bottles. As the quantity of water evaporated and used for the analysis was as much as 658 ounces, Mr Pagenstecher was able to determine the ingredients, even in the most minute quantities. In 1000 parts of water the following ingredients were found :

Carbonate of lime, 0,40526 ; carbonate of magnesia, 0,01900 ; silica, 0,03482 ; alumina, 0,00950 ; sulphate of soda, 0,07345 ; sulphate of lime with water of crystallisation, 0,30711 ; sulphate of magnesia, 0,14881 ; oxide of iron, a trace ; organic matter, a trace ; = 0,99795 : Loss, 0,03102 ; = 1,02897.

No fluates, phosphates, nor strontian, could be found. Mr Pagenstecher had the goodness at the same time to undertake the analysis of the waters of the *Aar* and the *Rhine*. The former was taken from the middle of the stream near *Bern*, when the weather was fine and the water perfectly clear ; and after twenty-four hours not the slightest trace of a sediment was to be perceived.

The *Rhine* water was taken near *Basel*, at some distance from the bank, also at a time when the river was perfectly clear. In the bottles in which it was sent there was no sediment, and the water was clear and colourless.

The analysis gave the following result.

	Aar.	Rhine.
Carbonate of Lime, . . .	1,52191	1,27916
Carbonate of Magnesia, . .	0,16824	0,1351
Silica, ...	0,02693	0,02083
Sulphate of Soda, ...	0,00862	0,01845
Sulphate of Lime, with water of crystallisation, ...	0,17420	0,15357
Sulphate of Magnesia, . . .	0,26005	0,03928
Chloride of Sodium, . . .	...	...
Chloride of Potassium, . .	0,00287	0,01488
Alumina and Oxide of Iron, .	a trace.	a trace.
Organic matter, ...	a trace.	0,03273
	2,16282	1,69401
Loss, ...	0,04992	0,01726
	2,21774	1,71127

If we compare the analyses of these three waters, we find a very near resemblance in their component parts: the only difference being, that in the *Lutschine* the chlorides are wanting which are found, although in but small quantities in both of the others. They do not, however, correspond so nearly in the quantities of the various parts ; on the contrary, the difference is here very great, for the *Lutschine* is distinguished by its far greater purity, that is to say, by its comparatively small contents of fixed sub-

stances. Yet it does not contain so little, as Mr Pagenstecher very justly remarks, as to lead us to suppose the water of the *Lutschine* to be only the product of the melting of the glacier, under which it takes its rise ; but from the nature of its ingredients we should be inclined to consider it as entirely composed of the water of springs, or at least, with but a small admixture of glacier-water.

The comparison of the water of the *Lutschine* with that of the *Aar*, can, indeed, give no certain data, as the latter is formed by the union of so many different springs and glacier-streams ; yet we cannot but be astonished to see that the quantity of fixed substances, contained in the water of the *Aar*, amounts to more than double that of the *Lutschine* ; and that the quantity of carbonate of lime in the former, is almost four times as great as in the latter. It is true that the country tributary to the *Aar* is for the most part composed of limestones ; but it is also true that the springs in the lower glacier of *Grindelwald*, as well as the glacier itself, are situated in similar rocks. Still it remains very remarkable, that the *Lutschine* should contain so little carbonate of lime ; and this is certain, either that the streams which flow into the *Aar* and do not proceed from glaciers, must be very rich in carbonate of lime, for this river, after receiving into it the *Lutschine*, and so many other glacier streams, probably containing a proportion of carbonate of lime, equal to that of the *Lutschine*, is yet found to be so exceedingly rich in this earth ; or that the *Aar* must dissolve a great deal of lime, during its course through the limestone mountains. The latter seems to be the more probable, since the *Aar*, as far as *Bern*, is supplied for the most part by waters proceeding from the glaciers. The smaller proportion of lime in the *Rhine*, at *Basel*, compared with that of the *Aar*, which shews that the *Rhine* must have contained a still smaller proportion previous to its union with the *Aar*, may perhaps be accounted for, by the whole of the country tributary to the *Rhine*, in the canton *Graubünden*, belonging to the primitive formation, except the northern part, which consists of clay-slate and lime.

None of the numerous fresh-water springs, which rise at the foot of the *Mettenberg*, and of the *Eiger* near *Grindelwald*, have yet been analyzed. However, I am in hopes that Mr Pa-

genstecher will add to his valuable experiments above mentioned, some experiments on some others of these springs, and then we shall be able to ascertain, whether the minimum of carbonate of lime in them is greater than in the water of the *Lutschine* or not. Not being in possession of such information, we will endeavour to answer this question beforehand, from other fresh-water springs rising out of the limestone rocks, and whose contents of carbonate of lime are known.

In 10,000 parts of a fresh-water spring, which rises out of the calcareous sinter near the *Laacher See*, I found 0.947 parts of carbonate of lime. In the *Pader*, which is formed by the union of a great number of fresh-water springs which rise out of the limestone at *Paderborn*, I found 2.5259 parts, and in the *Lippe*, which also rises out of the limestone, 2.265 parts of carbonate of lime. Schübler* found in the water, which issues from the limestone quarries of the *Wurtemberg Alp*, from 1.3 to 2.6 parts of lime, and in a fresh-water spring, which rises out of the same limestone, 2.2 parts. Several of the rivers of that country, as the *Neckar*, the *Ammer*, and others, gave him from 3.6 to 4.5 parts of carbonate of lime. All these waters contain, therefore, much more carbonate of lime, from twice to ten times as much, as the water of the *Lutschine*.† If, then, the springs, which rise also out of the limestone, and unite beneath the lower glacier at *Grindelwald*, contain at least so much carbonate of lime as the poorest of these springs, it would follow, that at the time when Pagenstecher analyzed the water of the *Lutschine*, it was mixed with more than an equal quantity of glacier-water. But as, according to Ziegler, the melting of the glacier could no longer be perceived, we may conclude, that the glacier continued nevertheless to melt away from underneath in its interior, where the cold of the atmosphere could not penetrate.

The currents of air in the channels in the glaciers may be compared with the ventilation in mines, for they are produced

* Kastner's Archiv. T. v. p. 1.

† Even in the *Laacher See*, a lake situated in a volcanic crater, and resting in some places on greywacke and clay-slate, far from any limestone rocks, I found 0.4030 parts carbonate of lime in 10,000 parts of water, which is nearly as much as was found in the water of the *Lutschine*.

by the same cause, namely, the difference of density between the air within and the atmosphere.*

If the space through which a glacier stream flows, between the under surface of a glacier and the soil on which it rests, may be considered as one continued channel from the cleft B, (in Fig. 1, Plate 1, to the ice-cavern A; then in summer, when the external temperature is above 32° , the temperature within being 32° , an uninterrupted current of air will issue from A. Hence the continual draught of cold air from the ice caverns, which is greater the higher the temperature of the atmosphere, and is consequently found to be more violent in the afternoon, growing weaker in the night, and almost ceasing towards break of day. Let us suppose, for example, as is the case with the lower glacier at *Grindelwald*, that $BC = 2140$ feet, let the temperature of the atmosphere be 86.0° †, and that of the air in the channel beneath the glacier 32° , then the density of the column of air A G will be to the density of the column A B as 10 to 11. The velocity of the motion of the air in the channel depends on the difference of weight between these two columns of air, both supposed to be perpendicular. If we express the weights of the two columns of air of 2140 feet high, by the heights of two columns of water of respectively equal weights, we shall find—

For BC (column of cold air),	.	.	399.9 lines.
For AG (column of warm air),	.	.	363.6 lines.
Difference,			<u>36.3 lines.</u>

For one square foot of the section of the channel, or of the column of air, this difference would be equal to the weight of a quarter of a cubic foot of water, equal to 16,5 lb. Supposing the channel there to have no outlet from A to B, and to be wider than its lower opening in the same proportion that the tube of a large bellows bears to its contracted aperture; then, according

* I am indebted for the following calculation to the kindness of my friend and fellow-traveller Mr Althans, architect to the smelting works at *Sayn*, with whom I held frequent consultations, during our visits to several glaciers, on the various circumstances related above, and the results of which I have made use in preparing this chapter.

† Ebel, vol. i. p. 6.

to Koch's tables,* that difference would cause a current of air to issue from A, with a velocity of about 100 feet per second. But since the channels of the glaciers are not entirely enclosed from A to B, but have many minor outlets in the clefts D, E, F, H, and I, through which the air escapes in summer, and as they are not contracted at A, but, on the contrary, are enlarged at the lower opening in glaciers which have caverns, and as they have many unevennesses within, a great velocity cannot possibly be supposed to exist. From the smaller clefts D, E, and F, the air will issue in summer as out of A, but it will rush into the clefts H and I, which are situated higher up, in the same manner as it does into B. At a certain height, therefore, there must be a limit between the fissures through which the air enters and those by which it escapes; and this limit must be situated higher than the mean height BC of the glacier, when the upper fissures, and particularly B, are together larger than the lower ones together with the opening A; whilst, on the other hand, it must be situated below the mean, when the upper fissures are together smaller than the lower ones. From this limit upwards, the various currents will descend in summer more rapidly, and will escape more rapidly below, in proportion to their different heights.

Let us suppose the velocity of the currents to be but one-tenth of that found above, still the volume of warm air introduced is very considerable; and as they must be cooled down during their long course through the glacier, nearly to 32° , it may easily be conceived how great an influence such currents of air must have in melting the glacier away from underneath, as well as in raising the temperature of the glacier-streams.

If the ice-caverns become completely blocked up in the winter, the currents of air under the glacier will be entirely stopped. But even though the glacier be covered with snow, yet all the fissures will not be got closed up so as to prevent the passage of the air; for many places will still be left, through which currents of air, though perhaps but inconsiderable ones,

* Experiments and observations on the velocity and quantity of compressed atmospheric air, which issues from apertures of various forms, and through tubes, &c. Gottingen, 1824.

will find a passage. But these currents will take a contrary direction in the winter, and will enter from below, and make their escape above, so long as the temperature of the atmosphere is lower than that of the interior of the glacier. However, these currents, which tend to cool the under surface of the glacier, can never be so considerable as those which take place in the summer, for the cold air cannot be warmed within the glacier above 32° , so that there can be but a small difference between the density of the atmosphere and that of the air within. The under surface of the glacier cannot, therefore, suffer any considerable depression of temperature during the winter, so that the hypothesis, that the soil beneath the glaciers remains at about 32° throughout the whole year remains almost unshaken.

It is probable that the piercing cold currents of air, which issue from the fissures, when a sudden change takes place in the temperature of the atmosphere, carrying fine grains of ice along with them, and scattering them, far and wide, like fine snow over the country,* take place when the external temperature suddenly sinks below $32^{\circ}.0$, by which the current is found to alter its direction, and to rush from the cavern towards the fissures above. For if the air which issues from the fissures at a temperature of 32° , be impregnated with humidity, when it enters an atmosphere of a temperature below 32° , the water must be frozen, and thus form the grains of ice. And this phenomenon is precisely analogous to one which I observed a short time since at the mouth of a shaft, during a sharp frost, where the warm air, which rose out of the shaft, deposited flakes of snow on the whim, and on the buildings over the shaft.

It is of importance to the study of the internal heat of the earth, to ascertain whether glaciers in general increase or not. The annual advance of the glaciers during the warm season, which Saussure† very simply explained by the under surface be-

* Ebel, part iii. 116. Gruner in his "Beschreibung der Eisgebirge des Schweitzerlandes." Bern, 1760, relates an example of this, witnessed by a friend of his, who travelled across a glacier in the middle of July.

† Voyages, i. p. 453. Escher in Gilb. Annal. vol. lxix. p. 113. Horner in the Neuesphysikal, Wörterbuch, vol. iii. p. 135. Against this opinion see

coming slippery by the melting of the ice, and thus allowing the glacier to slide down the sloping declivity, is a well known fact. Whether this advance be greater than the loss sustained by the melting away of the ice, depends not only on the warmth of the summer, but also on the greater or less quantity of avalanches, which fall during the winter on the upper part of the glacier. And this latter condition again depends not only on the quantity of snow which has fallen in the winter, but also on the direction which the avalanches take. But this direction may be modified by various local circumstances, by the change in the slope of the side of the mountains, caused by the falling in of large masses of rock, &c. Escher further observes, that, in warmer years, the side edges of the more elevated glacier, are often melted to a greater extent, and that that part of the glacier which is situated at the entrance of a cross valley, is thus more easily carried forward, and is forced in greater masses into the valleys below. Thus it may often happen, that some arms of a glacier increase in length for several successive years, whilst others, situated quite near them, become shorter.* It must be remarked, that the glaciers in elevated valleys extend down both sides of the mountain, and thus two or more arms or branches are formed, which meet together on the top of the ridge.

If the lower part of a glacier, by being kept slippery by the melting of the ice from its under surface, or higher up, by the melting of the upper surface, and the penetrating of the water to the under surface, slip down, the upper part, which only consists of loose snow, without any cohesion, will follow like an avalanche, and thus come into a region, when the snow will be converted into ice.

Besides the increase and decrease of the glaciers, caused by the above mentioned circumstances, it is a pretty general opinion

V. Charpentier in Gilb. Annal. vol. lxiii. p. 388, and Biselx in the same, p. 192. Kühn (Höpfner's Magazine, vol. i. p. 129), observed an advance of the lower *Grindelwald* glacier, accompanied with a violent subterranean noise, when he was on the *Eismeer*, by which several very wide fissures were suddenly closed, and the water which was in them forced up to a considerable height.

* Numerous examples of this are to be found in the Biblioth. Univ. xiv 285.

in the Alps that on the whole the glaciers increase. Thus Ebel* mentions in several places that, according to tradition, many elevated valleys, which are now quite filled with glaciers, were formerly fruitful.†

Whether these traditions, themselves not sufficiently confirmed, are enough to prove the increase of the glaciers to be a general phenomenon, is very doubtful.‡

This, however, is certain, that there are two causes which operate uninterruptedly in the Alps, and act in opposition to the increase of the glaciers. These causes are the wearing away of the earth beneath the glaciers, caused by their progress downwards, and by the continual running of the streams under them; and, secondly, the falling down of ridges and of high masses of rock.

When we consider that there is always a great quantity of stones and blocks of rock beneath the glaciers,§ which must sus-

* Part II. 302; III. 173; IV. 109, &c.

† Buffon, *Epoques de la Nature*, 6ème edit. Note justif. 31.—Bourrit, *des glaciers de Savoie*, Genève, 1773, p. 111. The same in his *Descrip. des aspects du Mont Blanc*, Lausanne, 1776, p. 8. 62.—Bergman, *physikal. Erdbeschreib.* Part II. p. 5. c. 2. § 157.—Altmann's *Versuch einer historisch phys. Beschreib. der Helvet. Eisgebirge*. Zürich. 1751. 141.—Schultes *ueber die Tyroler Gletscher* in *Gilb. Annal.* xx. 243; von Buch on those of Norway in the same, vol. xli. p. 22.—Pontoppidan, *Natürl. Historie v. Norwegen*, i. 56.—Hansteen in the *Edinburgh Philos. Journ.* x. 213. Against this, see Naumann in *Leonhard's Taschenbuch Jahrgang*, xvii. p. 163.—Scoresby *ueber die Gletscher in Spitzbergen*. *Gilbert's Annal.* vol. lxix. p. 142.—De Luc in the same, p. 149.—Charpentier in the same, vol. lxiii. p. 408.—Bisels in the same, vol. lxiv. p. 191.—Pictet in the same, p. 200.—Anmerk the same, vol. lx. p. 334.

‡ Von Welden (*der Monte Rosa*, Vienna, 1824, 78. 81.) Kasthofer (in his prize Essay in *Zschocke Ueberlieferungen*, 1820, 505 and 574;) Hegetschweiler (*Reisen in den Gebirgsstock zwischen, Glarus, and Graubünden in den Jahren, 1819, 1820, and 1822*, Zürich. 1825, pp. 11, 12, 41, 54, 103;) and Hugi (*Naturhistorische Alpenreisen*, Solothurn, 1831) mention indeed many examples of periodical advances and retreats of glaciers, but found no proofs of their absolute increase within thousands of years.—Venetz (see *Kastner's Archiv für Chemie und Meteorologie*, ii. 225) thinks himself entitled to conclude, from various geognostical phenomena, such as the occurrence of large loose blocks of rock on extensive plains, &c. &c. that the glaciers are in the act of retreating.

§ The immense heaps of *detritus* (Gandecken, Moraines) which are found below the glaciers, as well as at their sides, are a proof of this; besides which, we are told by the innkeeper at *Grindelwald*, who has become so celebrated by

to be

to

B

D

D.

more of

and thus a

is a well

less sustained

the way

of the

the

the

the

the

the

the

the

the

the

the

the

the

the

the

the

the

the

the

the

the

the

the

the

the

the

the

the

the

the

the

the

the

the

the

the

the

the

the

the

the

near *Müllinen*, are to be seen among others the same rolled stones which are now carried along by the *Kander*, some hundred feet lower. To this action of the deepening of the beds of glacier streams must be added the immense pressure sustained under the glaciers.

Let us suppose, that in a certain time the destruction of the rocks under a glacier proceed to a depth of 115 feet, the glacier will thus be brought down into a region in which the mean temperature of the soil is $2^{\circ}.25$ higher than before. It will now, therefore, be melted more rapidly ; and, if more is not supplied from above than before, it must suffer a decrease in size, nay, in a certain time it will disappear altogether. That many glaciers have actually decreased to a considerable extent in progress of time, is evident from the heaps of detritus (*Gandecken*), which are often found at a considerable distance from their present lower extremity.*

I am inclined to consider these evident signs of the former and present extent of glaciers, as more decided proofs of their decrease than the mere tradition of the formation of new glaciers is of their increase. However, I do not mean, by the above train of reasoning, altogether to deny that glaciers may also increase, and that new ones may sometimes be formed. It is only the universality of the phenomenon that I am calling into question. With regard to the second of the two causes given above, as acting in opposition to the increase of glaciers, viz. the falling in of high points of rocks, it is self-evident that glaciers must disappear, when the mountains covered with perennial snow, from which they are supplied, are destroyed. The hypothesis of Ebel,† that the northern side of the *Gemmi* to the *Dauben lake* was formerly covered with glaciers, is therefore certainly correct ; for we have evidence of this in the enormous fallings-in which have there taken place, probably in consequence of the

* For the sake of example, we may mention the *Gandecke*, already cited above, near the upper *Grindelwald* glacier ; that of the lower glacier, which is now covered with trees ; as well as that of the present *Rhone* glacier, which lies at a distance of 2404 paces from it. May not the heaps of detritus which are found in valleys at a great distance from any glacier, also have been formerly *Gandecken* ?

† Part III. pp. 30 and 338.

facility with which the slate on which the *Gemmi* rest is disintegrated, and hence the great heaps of detritus at the southern foot of the *Gemmi*, and in the valley of the *Rhone*. Traces of similar fallings-in of the rocks, and of extensive ancient glaciers, are also to be found on the northern side of the *Gemmi*, below the inn of *Schwarrbach*, and near the *Spital Matte*. On this Alp are seen several hills covered with fir-trees, and formed of blocks of limestone, disposed in irregular layers, one above another. Out of the innumerable clefts in these hills rise the numerous freshwater springs which we have already before mentioned, and which, after forming a considerable stream, sink into the rocks and reappear, together with several other springs at the foot of one of the smaller hills. Below *Kanderstäg*, on the left declivity of the mountain, we find a very large heap of detritus, which we are indeed inclined to consider as an enormous *Gandecke*. But even further down, as far as *Frutigen*, we see considerable hills composed of blocks of limestone heaped together, sometimes in the middle of the valley, and sometimes resting on the high mountains on each side. The luxuriant vegetation in the valley shews, as every where, that the soil here rests upon fragments broken off and precipitated down from the rocks above.* Traces of such dislocations are well known to exist in the Alps, and the history of recent times furnishes many melancholy examples of the same. Thus, for example, the sudden fall of the rocks, and the destruction of the city of *Plurs* or *Piuri* † in the year 1618,—that of the village of *St Abundio* ‡ in 1760,—the falling-in of the *Diablerets* in the years 1714 and 1749,§—that of the *Ruffi* or *Rigi* at various periods,—and the latest and most dreadful catastrophe of all, which filled the valley of *Goldau* with rubbish in 1806.||

Such disturbances must be frequently repeated, as the rapid streams below undermine the feet of the mountains, by which the rocks are made to split and to sink, the fissures sometimes extending more than a thousand feet above the bottom of the

* Escher in Gilbert's Annal. vol. lx. p. 363.

† Ebel, part ii. p. 365.

§ Ibid. p. 446.

‡ Ibid. p. 367.

|| Ibid. p. 146.

valley ; into these the waters enter in the following spring, soften the rocks, and thus cause their fall.*

The alternation of frost and thaw also causes the dislocation, and breaking done of considerable masses of rock. Thus Gérard observed in the *Himalaya* mountains, that masses of an enormous size were continually falling down from some rocks, between which there were passes, at a height of 15,000 to 16,000 feet. The bottom of the passes was covered with immense heaps of such fragments.†

But the universal consequence of such fallings in of the rocks will be, that the glaciers will lose their supply of snow, and will decrease, or perhaps entirely disappear. Thus by degrees many spots are reclaimed from the regions of perennial snow, and become capable of sustaining organic life.

CHAP. X.—*The frozen soil of northern Siberia is no contradiction to the increase of temperature towards the interior of the earth.*

The whole of northern *Siberia* presents the singular phenomenon, that, even in the hottest season, the soil remains frozen from a certain depth downwards, differing according to the latitude, and other local circumstances, and that the thickness of this frozen stratum is so considerable in the more easterly places, as, for instance, at *Jakutzk*, that its bottom has not yet been reached.‡ Gmelin relates that in the archives at *Jakutzk*, he found an account of an inhabitant of that town having, at the beginning of the last century, together with some *Jakuters*, contracted to sink a well, and that when they had

* We have proofs of the decrease of the height of the Alps in former times, in the loose blocks of rock which lie scattered about in all directions, as it seems certain, from the observations hitherto made, that they have been precipitated from the upper Alps. *Die Umwälzungen der Erdrinde von Cuvier*, translated by Noggerath, 1830. ii. p. 15. It is also proved by the deposits from the alpine streams in places where their course is less rapid, by which means enormous masses have been and still continue to be carried out of the the Alps.

† N. Geograph. Ephemeriden. xiv. p. 262 and 276.

‡ To this phenomenon is to be ascribed the existence and the good preservation of the great tropical animals, covered with their flesh and other soft parts, found at the mouth of the *Lena*, and on the banks of the *Willhui* in latitudes 72° and 64°.

reached the depth of 90 feet, finding the earth still frozen, they refused to fulfil their engagement.*

Some philosophers have considered this contradictory to the supposition that the interior of the earth is in the state of fusion. But from the following account it will be seen that, in those frozen strata, the general phenomenon of an increase of temperature with the depth is not wanting, and that by continuing the work, they have arrived at a temperature which leaves no doubt that they are not far from the lower limits of the frozen soil, and that water, the object of their undertaking, is not far distant.

It is well known, says an article from *St Petersburg*, in the Berlin news of the 24th February 1832, that at *Jakutzk* in *Siberia*, the earth, even in the hottest summer, only thaws to about the depth of three feet. Hitherto all attempts to discover the thickness of the frozen strata beneath, have been fruitless. Since the year 1830, one of the inhabitants of *Jakutzk* has been engaged in sinking a well, by which means it may, perhaps, be ascertained. In the same year the workmen reached the depth of seventy-eight feet below the surface, but still found no water. In the year 1831, they reached ninety feet, and were still in the frozen soil. The work is still in progress, and there seems no doubt of their attaining their object, for the thermometer, which shewed $18^{\circ}.5$, a few feet below the surface, rises, when sunk to the bottom of the well, to $29^{\circ}.75$.†

It is evident that in high latitudes, where the mean temperature of the soil is below 32° , there must exist a frozen stratum of earth of a certain thickness, which can only thaw during the summer, to that depth beyond which the influence of the external temperature is no longer felt. For, in the same manner as in our climates, the soil is frozen to a certain depth by the cold of winter, so must the frozen soil, in those high latitudes, be thawed to a certain depth by the heat of summer. In *Siberia*, the temperature of the soil is near 32° , in the latitudes of the *North of England* and *Scotland*; for Von Humboldt and Adolphus Er-

* Against this, see V. Buch in Poggendorff's Annal, vol. xii. p. 405.

† See Erman, in Poggendorff's Annal., vol. xvii. p. 340, Von Humboldt, ibid. vol. xxiii. p. 104 and 106, and Hansteen, ibid. vol. xxviii. p. 584.

man found wells and springs of $33^{\circ}.3$ to $34^{\circ}.4$ in the months of July and August, in such latitudes. At *Jakutzk*, therefore, in 62° North Lat., the mean temperature of the soil must already be considerably below 32° . Thus, if we suppose it to be only 27° , and that the temperature increases towards the centre of the earth at the same rate as it has been found to do in our climates, the mean temperature of the earth would not reach the melting point of snow until a depth of 230 to 256 feet.

CHAP. XI.—*The decrease of Temperature in the Waters of the Sea and of Lakes, is not contradictory to the hypothesis of an increase of Temperature towards the Centre of the Earth. On the contrary, we can only explain the Temperature of Sea and of Lakes by admitting an increase of Temperature towards the Centre of the Earth.*

De Saussure * determined the temperature of the *Swiss Lakes* at various depths, as in the following table:—

Places.	Temperature of the Water		Depth in feet.	
	on the Surface.	at the Bottom.		
Lake of Geneva, ...	42.09	41.74	950	1777, Feb. 6.
Do. do.	70.13	43.09	150	1775, Aug. 5.
Lake of Thun, ...	65.5	41.00	350	1783, July 7.
Lake of Brienz, ...	66.24	40.69	500	1783, July 8.
Lake of Lucerne, ...	68.49	40.74	600	— July 28.
Lake of Boden, ...	63.59	40.00	370	1784, July 25.
Lago Maggiore, ...	77.00	44.03	335	1783, July 19.
Lake of Neufchatel, ...	73.59	41.00	325	1779, July 17.
Lake of Biel, ...	69.23	44.34	217	1779, July 20.
Lake of Annecy, ...	57.84	42.09	163	1780, May 14.
Lake of the Bourget, ...	63.24	42.09	240	1781, Oct. 6.

According to De la Beche's observations on the *Lake of Geneva*,† the temperature of the water, at depths of forty to seventy fathoms, seems everywhere to be $43^{\circ}.9$, except only at *Ouchy*; and from eighty fathoms downwards to the greatest depths, he

* Voyages aux Alpes, § 1351 and 1391.

† Gilbert's Annalen, vol. lxvi. p. 146.

found a constant temperature of $43^{\circ}.04$. In lesser depths than forty fathoms, the temperature varies according to circumstances, but to that limit it always decreases from the surface downwards. In the *Lake of Thun*, De la Beche found the temperature at the surface to be $59^{\circ}.9$, whilst at a depth of 105 fathoms it was $41^{\circ}.4$; and in the *Lake of Zug* the temperature on the surface was 58° , whilst at a depth of thirty-eight fathoms it was 41° . Three hundred to four hundred fathoms deep in the *Lago di Como*, Volta found a temperature of $43^{\circ}.2$.* On the 16th April 1798, Von Humboldt found the temperature of the water of the *Lake of Barthomew*, in the *Berchtesgaden Alps*, at a depth of 2 feet, to be $45^{\circ}.83$; at 42 feet, $43^{\circ}.18$; at 60 feet, 41° ; and at another spot, at a depth of 84 feet, $42^{\circ}.09$.† Recent measurements of D'Urville,‡ and of Boubée in the *Lake of Oo*, near *Bagnères de la Chou*,§ have given the same results.

Thus we find that the temperature in the depths of lakes approaches that of fresh water at its greatest density, which, according to the latest accurate experiments of Stampfer, is $38^{\circ}.7$.||

On the temperature of the sea in various depths, numerous observations have been made, sometimes giving contradictory results, which may have been partly owing to the various methods and instruments used.

From more than fifty observations, made by Castberg ¶ on the temperature of the water, at depths varying up to 200 feet on the coast of the *Mediterranean*, he found no regular variations. Peron** concludes from his own observations, as well as from those of Irvine and Forster, 1st, That far from the coast, the temperature of the sea is lower at all depths than at the surface, and that it decreases with the depth, apparently according to a certain law; 2d, That this holds good, as well for the frozen seas of the polar regions, as for the burning climates un-

* Gilbert's Annal. vol. ii. p. 402.

† Reise in die Acquin. Gegend. iii. 132. ‡ Bibl. Univ. 1833, Nov. 323.

§ London and Edinb. Phil. Mag. 1832, p. 383.

|| Jahrbücher des K. K. Polytechnischen Instituts zu Wien, vol. xvi. p. 48.

¶ Gilbert's Annal. vol. xix. p. 344.

** Annales du Museum d'Hist. Nat. t. v. p. 123 to 148, and Journ. de Phys. t. lix. p. 361. Also in Gilbert's Annalen, vol. xix. p. 427.

der the equator; only that at equal depths, the cold is comparatively much greater near the poles than under the equator. But he goes further, and concludes from this, that the deepest abysses of the sea, as the summits of our mountains, are covered with perpetual ice, even under the equator, and therefore considers that so many facts are sufficient to overthrow the hypothesis, now so generally adopted, of the existence of fire in the centre of the earth.*

Von Buch† came forward in opposition to this last conclusion, and declared himself hostile to the formidable idea of the existence of such a crust of ice, which is by no means rendered necessary by observation. If, says this ingenious philosopher, the internal cold is felt so near the surface of the sea, should it not also be felt at those depths in the earth near the sea, which are so distant from the surface that the latter can no more have any heating effect on it? But has there ever been found in the

* Peron (*Annales du Museum d'Hist. Nat.*, vol. v. p. 123 to 148, and *Journ. de Phys.*, vol. lix. p. 361) found several zoophytes, fished up from the bottom of the sea on the coast of *New Holland*, to be $6^{\circ}.75$ warmer than the air and the surface of the sea. He puts the question, Whether the zoophytes inhabiting the bottom of the sea live as the more perfect animals and plants do, in a warmth peculiar to themselves, exceeding, at least in some cases, that of the surrounding medium? It is a matter of doubt whether plants do possess a warmth of their own (see Treviranus, *Biologie*, vol. v. p. 3 and following). According to all observations, namely, those of Schübler (*Poggendorff's Annal.* vol. x. p. 581), this is by no means the case. Among animals, birds have the highest temperature; next to them the mammalia; then the amphibia, fish, certain insects; and lastly the molluscae, crustacea, and the worms (John Davy in the *Edinb. Phil. Journ.*, vol. xiii. p. 300, and vol. xiv. p. 38). But if, as J. Davy asserts (in a letter to H. Davy of the 18th May 1816, in the *Journ. of Science*), the temperature even of fish is only $2^{\circ}.025$ to $2^{\circ}.700$ higher than that of the water, (see in opposition to this Von Humboldt and Provençal in the *Mem. de la Soc. d'Arc.*, vol. ii. p. 598), the temperature of the zoophytes must be scarcely perceptibly higher than that of the water. Should the zoophytes, notwithstanding, show a higher temperature, which, however, remains to be proved by more accurate observation, it ought rather to be supposed that such heat is derived from the bottom beneath, and that they retain it longer than the surrounding water does, which, by becoming specifically lighter, rises and carries its excess of heat to the surface, than that it is a heat peculiar to itself.

† Gilbert's *Annal.* vol. xx. p. 341.

wells of *Amsterdam*, which are sufficiently deep, a temperature sensibly lower than the mean temperature at the surface? Yet, notwithstanding the remarks communicated by Von Buch already thirty years ago, Parrot has lately again attempted to bring forward the decrease of temperature of the sea, and of lakes, in proportion to the depth, as an objection to the increase of temperature towards the centre of the earth.* But this objection has been silenced by Klöden.†

The decrease of temperature in the sea, in proportion to the depth, has also been confirmed by Captains Ross and Sabine, as well as for the northern ocean by Lieutenant Parry.‡ On the other hand, Lieutenant Franklin found the temperature sensibly higher, in high latitudes, at great depths in the *Greenland Sea*, than near the surface, and the difference was frequently as much as $9^{\circ}.00$ or $11^{\circ}.25$. Other officers of this expedition, Lieutenants Beechy and Fisher, observed the same. As most of Franklin's observations were made whilst the ship was surrounded with ice, the temperature of the surface of the sea must have been about the freezing point, which was probably the cause of his contradictory results. § These observations can, therefore, not be taken into consideration in the comparison of the temperature of the sea at its surface, and at various depths.

We are indebted for a valuable series of observations on the temperature of the sea at various depths, to an observer in whom the utmost reliance may be placed, namely, the astronomer who joined Krusenstern's Voyage of Discovery, the late Horner || of *Zurich*. He found that the temperature of the sea invariably diminishes as the depth increases. But single spots are to be found in the sea, where the temperature is greater in the depths than at the surface. Hot springs and volcanic action may cause considerable partial elevations of temperature in the sea, as, for

* Von Leonhard und Bronn *Jahrbücher der Mineralogie, Geognosie, Geologie*, &c. 1830, fasc. 3. p. 334.

† Ibid. 1831, fasc. 4. p. 384.

‡ Alex. Marcet's lecture before the Royal Society of London, 20th May 1819.

§ See Gilbert's *Annal.* vol. xx. p. 254.

|| Ibidem, vol. lxiii. p. 266, and following.

example, seems to be the case in the *gulf stream* on the coast of *America*, where, on hauling up the lead from a depth of 80 or 100 fathoms, it is so hot as scarcely to allow of its being handled. Similar spots seem to exist near the *Kurile Islands*, in *Basse's Straits*, and in the *Atlantic Ocean* where Horner in clear weather observed, at about nine miles' distance from the vessel, a cloud of vapour, which, during a quarter of an hour, continued alternately appearing and disappearing from the surface of the sea, and could neither be the smoke of powder nor that of a vessel on fire. Horner considers that this phenomenon may perhaps have been caused by a volcanic eruption. In opposition to the opinion that the bottom of the sea must in very great depths consist of a solid mass of ice, Horner brings forward very conclusive arguments.

Lastly, a series of observations were made by Lenz,* on a voyage round the world, under the command of Captain Von Kotzebue, in the years 1823 to 1826, with the utmost care and circumspection, so that particular confidence may be placed in them. They yielded the following results:—1st, Between 45° north latitude and the equator, the temperature of the ocean constantly decreases to the depth of 1000 toises, below which no experiments have been made. 2d, The decrease of temperature is at first rapid, but becomes slower and slower, and is at last scarcely perceptible. 3d, The point at which the decrease begins to be imperceptible, seems to be situated less and less deep the further we recede from the equator. Under latitudes 41° and 32° , its depth is 200 to 300 toises; in latitude 21° , it is 400 toises. 4th, The lowest temperature observed in great depths, was $35^{\circ}.93$, and this is about the temperature of all points where the decrease begins to be no longer perceptible.

According to the third mentioned result, this temperature is found nearer to the surface the higher the latitude; it would be interesting to ascertain in what latitude it reaches the surface.

We will now proceed to the consequences which may be deduced from the decrease of temperature in the sea and in lakes.

* Poggendorff's Annal. vol. xx, p. 73 and following, extracted from a paper read by Lenz before the Academy of St Petersburg, on the 4th of November 1829.

From the above observations on the temperature of the lakes in *Switzerland*, which were made at various seasons of the year, we see that the temperature on the bottom approaches very near to the degree at which water assumes its greatest density ; but never quite reaches it. It is always $1^{\circ}.35$ to $5^{\circ}.74$ higher than $38^{\circ}.7$. Suppose a lake in the autumn to have everywhere in its depth a temperature of $54^{\circ}.5$; and that the water neither gives nor receives heat from the earth on which it rests. Now, if cold set in, and the surface of the lake be depressed below $54^{\circ}.5$, the water at the surface becoming more dense, will sink to the bottom, and continue to do so until it be everywhere reduced to $38^{\circ}.7$. If the cooling of the surface continue still further, it will have no more influence on the temperature of the water below ; for now the water at the bottom of the lake can only become colder by imparting its heat to the colder water above ; which, however, cannot take place, water being so bad a conductor of heat, and the lake having so great a depth. The lake will therefore have a temperature of $38^{\circ}.7$ from the bottom, nearly to its surface. If the temperature at the surface then begin to rise again, the only increase which will be caused in the temperature of the water below, will be by the communication of its heat. But for the reason just mentioned, this cannot extend far ; and, in fact, the observations of De la Beche gave equal temperatures at depths of 40 to 70 fathoms ; and also at depths of 80 to 174 fathoms. They shew farther, a decrease of $22^{\circ}.50$ from the surface to 40 fathoms ; but from that depth to 164 fathoms, which is a depth four times as deep as the former, only 0.450 . We may, therefore, imagine a stratum of water below 40 fathoms, acting as an absolute non-conductor of heat from above. From De la Beche's observations, this stratum may have a thickness of 30 to 84 fathoms. It is consequently difficult to conceive how the temperature at the bottom of the lake should ever exceed $38^{\circ}.7$, especially since at least twice in each year the surface of the lake falls to $38^{\circ}.7$, at which seasons the stratum of water bearing that temperature increases in thickness. If, notwithstanding, we find the temperature at the bottom of the *Swiss Lakes*, at all seasons, $1^{\circ}.35$ to $5^{\circ}.74$ higher than $38^{\circ}.7$, the water must have obtained that excess of temperature from another source, and there is no other source of heat left but the earth.

In opposition to these conclusions it may be remarked, that the water, when cooled at the surface by the air, does not sink with its reduced temperature quite to the bottom, but becomes somewhat warmed again during its descent, at the expense of the warmer layers of water, through which it passes. And this is undoubtedly the case. But since the sinking of the cold currents of water must necessarily be attended with the rising of the warmer water from below, which in its turn is also cooled when it comes to the surface; it follows, that during the continued cold of winter, the water at the bottom must at one time be reduced to a temperature of $38^{\circ}.75$. And if this should even only take place once during a severe winter, there being no communication of heat from above, it seems difficult to account for a temperature of $1^{\circ}.35$ to $5^{\circ}.67$ higher than $38^{\circ}.75$, otherwise than by supposing it to be due to heat supplied from the earth. Muncke* ascribes this higher temperature to the action of the sun, as De Saussure's observations were not made till May. But can it be supposed that the rays of the sun penetrate to such a considerable depth as that in which the observations were made, and are still capable of having any effect, when we consider how very rapidly the transparency of water decreases with the depth? It is true that Saussure's observations in the *Lake of Geneva*, in the months of February and August, show an increase of $+1^{\circ}.26$; but this difference might perhaps be overlooked, when we consider the great difference of the depths.

If the water at the bottom of lakes should become heated by the earth beneath, there will be a stream constantly flowing upwards, which will rise higher the less the temperature at the surface exceeds $38^{\circ}.7$. This stream will reach to that height in which the temperature of water is equal to that of the stream. This stream will continue to rise only so long as the temperature at the surface does not vary. But if a depression take place, there will also be a descending current which will fall to that depth in which the temperature of the water is equal to its own. If the temperature of the lake from its surface to a great

* Gehlers neues physikal, Worserbuch. viii. 742. in note.

depth, be thus reduced to $38^{\circ}.7$, the descending current will cease. In this state it will continue whether the temperature decrease towards 32° , or to whatever degree it rise. The descending current will not again come into action until the temperature at the surface, having risen above $38^{\circ}.7$ shall again begin to decrease. Whilst the temperature at the bottom of the lake is $38^{\circ}.7$, or near $38^{\circ}.7$, and at the surface 32° , the water having a temperature between 32° and $38^{\circ}.7$ may be heated by the currents made to ascend by the warmth of the earth, as high as $46^{\circ}.79$, without those currents reaching the surface; for at $46^{\circ}.79$ water has the same specific gravity as at 32° .

Observations on the temperature of lakes at different depths during the time when the temperature at the surface remains constant at 32° would give interesting results. For, according to the above reflections, the temperature ought to increase from the bottom up to a certain height, and then continue decreasing up to the surface. But nowhere could the temperature rise above $46^{\circ}.79$, so long as the water at the surface remained at 32° .* The only instance of an observation being made at a great depth, at a time when the temperature at the surface was near 32° , is that of Saussure of the 6th of February 1777, when he found the temperature at the surface $41^{\circ}.74$, whilst at a depth of 950 feet it was $42^{\circ}.09$.

Lakes receive a greater quantity of heat from the earth, the hotter the climate is in which they are situated, and the deeper they are. This quantity of heat, therefore, depends on the latitude of the lakes, their elevation above the surface of the sea, and their depth. The actual temperature of the bottom of a lake cannot, it is true, be higher than that of the water immediately in contact with it, and consequently, not much above $38^{\circ}.75$; but more heat will be communicated from the interior of the earth, the warmer the strata are which lie immediately beneath the bottom of the lake. Near the *Lake of Geneva*, a temperature of $62^{\circ}.8$ was found in a sounding well at the depth of 680

* I may perhaps have an opportunity of making such observations in the *Laacher See*, where a depth of 200 feet has been found, without there being any reason for supposing that to be the deepest spot.

feet. The same temperature would of course be found at the same depth on the bottom of the lake, if it were entirely filled up with the solid masses which compose our globe. But 680 feet is not the greatest depth of the lake, for it measures as much as 950 feet in some parts. Supposing the increase of temperature to proceed in the same proportion as was observed in the neighbouring sounding, a temperature of $68^{\circ}.34$ would be found to prevail at the depth of 950 feet. These thermometrical relations, which must be imagined quite independently of the lake, were doubtless interrupted at the moment of the formation of the lake, but yet not entirely destroyed.* We may therefore still be allowed to assume $68^{\circ}.34$ for the temperature of the bottom of the lake, at a depth of 950 feet, although its actual temperature must be the same as that of the water at the same depth, which, according to Saussure, is $47^{\circ}.72$. We have therefore to distinguish between the actual temperature of the bottom of the lake, and that which it would have, considering only its latitude, its elevation above the sea, and its depth. The difference between them is the thermometrical expression, or as it were a measure, for the heat communicated from the earth to the water, and with it carried to the surface. Thus this thermometrical expression would be for the *Lake of Geneva*, at a depth of 950 feet, $68^{\circ}.34 - 47^{\circ}.72 = 20^{\circ}.62$. The positive quantity of heat which escapes from the bottom of the lake into the water, however, depends on the degree of conductivity of the earthy and rocky strata which lie beneath it.

In lakes, therefore, relations exist similar to those in the glaciers, namely, that there rests upon a certain surface a mass, in the one case of snow and ice, in the other of water, which con-

* With respect to this, I cannot agree with my friend Professor Muncke, who considers that the source of heat at the bottom of the lakes must already have been exhausted by time. See Gehler's n. Worterb. as above. Such a supposition could only be admitted, if we could consider the bottoms of lakes to a considerable depth as non-conductors of heat. But for such a supposition there are no grounds. To whatever depth, then, the cooling influence of the water is felt in the earth, from the same depth will the warming influence of the interior of the earth be able to exert itself; that is to say, the water at the bottom of the lakes will receive heat from the interior of the earth.

tinually exerts a cooling influence upon it, and reduces its temperature below that which it would otherwise have from its latitude and elevation above the sea. But since this surface is connected with strata of a higher temperature by means of a conducting medium, heat must, according to the conducting power of those strata, be continually communicated to the cooling mass. In the case of the glaciers this heat is employed in melting the snow and ice, but in lakes it is carried to the surface by the ascending particles of water. Here it either assists in promoting the evaporation of the water, and thus becomes latent, as in the glaciers, or it raises the temperature at the surface. Whether both these take place at the same time, which it is most probable they do, might be ascertained by corresponding observations on the temperature of the surface of a lake and of the earth in its immediate vicinity. Such observations, which it would be necessary to continue for a whole year, in order to obtain the mean, would therefore decide a very interesting question.*

* The annual meteorological report of *Wurtemberg* for 1831, contains the thermometrical observations in the *Lake of Constance* and the surrounding atmosphere, made by Dr Dihlmann, in July 1831, daily at two o'clock P. M. The mean of the former is $77^{\circ}.25$, that of the latter $79^{\circ}.02$. As the observations were made at the time of the daily maximum, the true mean temperature of the *Lake of Constance* must be lower than $77^{\circ}.25$. According to observations which I made during a journey by steam to *Strusburg*, on the 19th and 20th of August 1835, on the temperature of the *Rhine*, the greatest daily difference was $1^{\circ}.8$ to $2^{\circ}.25$. The true mean temperature of the *Lake of Constance* in July 1831, may therefore be estimated at about $76^{\circ}.12$. But from the mean temperature of the air a far greater deduction must be made. At *Stuttgart*, whose climate must be very nearly the same as that of the neighbourhood of the *Lake of Constance*, the mean temperature in July 1831 was $67^{\circ}.32$. According to this the mean temperature of the *Lake of Constance* must in that month have surpassed that of the surrounding atmosphere by about $9^{\circ}.00$. In the colder seasons this difference is probably not less considerable, as the water which is cooled by the air at the surface continually sinks, whilst the ascending currents must take place to nearly the same extent in winter as in summer. From this it may therefore be concluded, that the mean temperature of the surface of the *Lake of Constance* is higher than that of the soil in its vicinity.

Ten observations on the temperature of the *Lake of Constance*, made by Dihlmann in June, July, and August 1828 (from the 13th June to the 20th August), in the afternoon and evening, gave a temperature $5^{\circ}.85$ higher than the mean temperature of the air on those days, and only $2^{\circ}.47$ lower than the temperature of the air in the shade, at two o'clock in the afternoon. Similar

So long as the temperature of the bottom of a lake be above $38^{\circ}.75$, currents of water will continue to rise, but they will rise more feebly, and with a smaller increase of heat, the nearer the temperature of the bottom approaches that of the maximum density of water. If in higher latitudes, or in greater elevations, the temperature of the bottom of a lake does not exceed $38^{\circ}.75$, an equilibrium will take place: the bottom of the lake will neither receive heat from the water nor communicate heat to it, and the lower beds of water will never be warmer than $38^{\circ}.75$. If, lastly, the temperature of the bottom of the lake fall below $38^{\circ}.75$, the water which was cooled by the air at the surface will sink to the bottom, and there become still more cooled by coming into equi-

differences had been observed the preceding year. See Schweigger, Seidel's *Jahrb. der Chemie, &c. &c.* vol. lix. p. 32. Nineteen observations on the temperature of the *Lake of Constance*, between the 23d May and 30th July 1830, taken at three o'clock p.m., gave a mean temperature which was $3^{\circ}.60$ lower than the mean temperature of the air during the same period. Schweigger Seidel's *Jahrb.* vol. lxxv. p. 57. There is, therefore, no doubt that the mean temperature of the air during this period was also lower than that of the surface of the lake. During frosts the mean temperature of lakes must be higher than that of the air, as the temperature of the water cannot fall below 32° , whilst that of the air descends several degrees below 32° . During the severe cold in January and February 1830, the *Lake of Constance* was frozen over: a phenomenon of very rare occurrence. Schweigger Seidel, as above, p. 36. 5000 feet from the shore, the temperature of the air was $72^{\circ}.50$; 2000 feet from it, $-15^{\circ}.25$; that of the water itself, near the ice, varied on different days from 32° to $+33^{\circ}.35$. After the 31st January the lake froze almost entirely over, a small circle only, opposite to the *Friedrichshafen*, where the lake has the greatest depth, remaining open, but covered with islands of ice. Up to the end of January the thickness of the ice near *Uttweil* was found to be:

10,000 feet distant from the shore,	.	$6\frac{1}{2}$ inches.
15,000 	.	5 ...
20,000 	.	4 ...
30,000 	.	$3\frac{1}{2}$...

If, at the commencement of the frost, the surface of the lake becomes gradually cooled down, and thus gives rise to descending currents of water, which continue until the temperature of the surface reaches $38^{\circ}.75$; this period will naturally happen later in the deeper parts, than where the depth is less considerable; for there is a greater quantity of water, of a temperature above $38^{\circ}.75$ in those parts, and so long as water above $38^{\circ}.75$ exists below, the descending currents will continue to take place. So that the deeper the lake is, the later will its surface be reduced to $38^{\circ}.75$, and consequently also to the freezing point. If the depth of the lake should be found to increase in the

M. Bischoff on the Temperature of

librium with the temperature at the bottom. If in this case the lake be cooled down to $38^{\circ}.75$ up to the surface, ascending currents will again take place, the temperature of which will be below $38^{\circ}.75$, and the upper beds will be cooled down by degrees. But if the surface of the lake be warmed to as many degrees above $38^{\circ}.75$ as the bottom is cooled below $38^{\circ}.75$, no current whatsoever will take place.

Such relations must exist in the elevated alpine lakes, for example, on the *Gemmi*, the *Grimsel*, *St Gothard*, *St Bernhard*, and so forth, where the mean temperature at the bottom of the lakes is near 32° . It would therefore be very interesting if observations were to be made on the temperature in the depths of such lakes. For this purpose the small lake near the monastery on the *Great St Bernhard*, which has a depth of 33 feet, is pecu-

direction in which the above observations were made, this would be another argument in favour of our hypothesis. The increase of temperature observed in receding from the shore, seems to be connected with this phenomenon. For as the surface of the earth on the shore was cooled to a much greater degree than the ice, the temperature of the air near the shore must be found lower than at a greater distance from it.

It is very much to be wished that accurate observers may on future occasions keep these points in view, in order that they may, by means of observations directed immediately to this subject, place that in a clear light which at present can only be given as conjecture.

Von Humboldt (Reise, &c.—III. 131) mentions, that the temperature at the surface of the *Lake of Valencia*, during his stay in the valleys of *Aragua*, in the month of February, remained constantly between $73^{\circ}.4$ and $74^{\circ}.75$. It was from $1^{\circ}.08$ to $2^{\circ}.34$ below the mean temperature of the air, whether in consequence, as he remarks, of the evaporation, by which the water and the air are deprived of a portion of their heat, or because the changes of temperature in a large body of water do not keep equal pace with those of the air, and because small streams run into the lake, proceeding from several cold springs on the neighbouring mountains. But as this philosopher found in *Cumana* that the temperature of water, after having been exposed to the sun in vessels during seven or eight hours, was always $1^{\circ}.8$ to $3^{\circ}.24$ lower than the temperature of the air in the shade; then, supposing the depression of temperature, caused in the lake by evaporation, to be equal to this, we should have for the real temperature of the lake, independently of this depression, a degree $0^{\circ}.720$ to $0^{\circ}.9$ higher than that of the air; without taking the other causes of a depression of temperature into consideration. We are therefore justified in assuming that rising warm currents of water also exist in the *Lake of Valencia*.

liarily adapted. From the above train of reasoning it would be expected that such lakes would freeze to the bottom in winter; but, according to Bieselx,* the last mentioned lake, although it remains frozen during eight to nine months, is usually covered with ice of only 2 feet to $2\frac{1}{2}$ feet in thickness.† If this assertion is true, it is indeed somewhat difficult to conceive how water, inclosed from above with ice, and from below with a ground of a temperature not surpassing the freezing point, should be able to remain liquid. Could the total want of motion in the water, after being covered with a layer of ice, be the cause of its remaining liquid?

Such observations would, on the other hand, be a means of easily ascertaining the temperature of the soil in elevated regions, if that temperature were $38^{\circ}.75$ or below $38^{\circ}.75$, for then the temperature of the water in the depths would very nearly coincide with that of the bottom of the lake. It must, however, here be taken into consideration, that, if streams issuing from glaciers of a temperature nearly equal to $38^{\circ}.75$ flow into the lake, this will have an influence on the temperature of the lower strata of the water. During the warm season it may easily happen that streams issuing from glaciers, if they fall into the lake at a certain distance from the glacier, should have a temperature nearly equal to that of water at its maximum of density. I have also found several glacier-streams of such a temperature in the month of August at a distance from their source. But if the temperature of the lower strata of the water be $38^{\circ}.75$, and the glacier-streams warmer or colder than $38^{\circ}.75$, they will not reach the bottom of the lake. Thus, then, it may happen that lakes, in which the temperature at the bottom is above $38^{\circ}.75$, and into which glacier-streams of a lower temperature are emptied, may be thereby so cooled down at their surface that the heat rising from the bottom will be compensated, and consequently that the mean temperature at the surface will not be found to exceed that of the

* Gilbert's Annalen, vol. lxiv. p. 202.

† The water of this lake is also so cold throughout the rest of the year that no fish can live in it. I found the temperature of the surface of the lake of *Dauben* on the *Gemmi* to be $51^{\circ}.13$, the temperature of the air being $46^{\circ}.17$; and that of the small lake on the *Faulhorn* at $43^{\circ}.50$, when the temperature of the air was $36^{\circ}.50$.

bottom of the lake. This case cannot of course occur in the *Lake of Constance*, mentioned above by way of example.

When the rocks which compose the bottoms of lakes, in which the temperature at the bottom is $38^{\circ}.75$, are very much fissured, water of this temperature will escape from them. If such water reappear as springs at a lower level, the springs will have a temperature nearly equal to $38^{\circ}.75$. Thus I found the above mentioned springs (chap. iv.) on the *Spital Matte*, which probably proceed from lakes situated above, to have a temperature between $37^{\circ}.6$ and 40° .

If the temperature of the air over a lake never fall so low as that degree at which water possesses its maximum of density, no layers of water can possibly be met with in the depths having so low a temperature as that. For the lowest temperature of the air in the cold season is the minimum of the lowest temperature of the water in the depths. From this it follows, that in the plains of the torrid zone, or in low valleys, where the mean temperature is between $77^{\circ}.90$ and $80^{\circ}.60$, the bottoms of lakes can never be below $69^{\circ}.80$ to $71^{\circ}.60$. *

In the sea, the cooling of the water at the bottom must proceed further, for the greatest density of sea-water is far below $38^{\circ}.7$. Marcet† has shewn that sea-water continues to contract and to increase in weight until it freezes to a solid body; since which a series of experiments have been made by Erman jun.,‡ by which he found that salt-water of a specific gravity of 1.027 has no maximum of density, so long as it remains liquid, and even when ice is formed in it, the remaining liquid part continues to increase very considerably in density. But this property must also belong to the water of the sea, which, according to Gay Lussac,§ from an average of fifteen experiments, possesses a specific gravity of 1.0286 at a temperature of $46^{\circ}.4$. If, then, as Erman jun. asserts, sea-water offers no anomaly in its contraction between $+8^{\circ}$ and $25^{\circ}.2$, it is possible that in northern latitudes water may be met with in great depths in the sea of $25^{\circ}.2$.

* Von Humboldt Reise etc. iii. 133.

† In the paper read before the Royal Society of London, alluded to above.

‡ Poggendorff's Annal. vol. xii. p. 463.

§ Annal. de Chimie et de Phys. vols. vi. and vii. 1817.

The lowest temperatures of sea-water in great depths were observed by Irvine and Horner. On the 20th of June, the former found a temperature of $27^{\circ}.5$ at a depth of 3900 feet, in 67° N. Lat.; and the latter observed a temperature of $28^{\circ}.4$ in the *Sea of Ochotzk* between 30 and 115 fathoms deep. Horner conjectures that this degree is the limit below which the temperature of the sea never falls.

These temperatures are, then, still $2^{\circ}.25$ or $3^{\circ}.150$ higher than $25^{\circ}.2$. From which the same consequence may be deduced which was concluded from the above observations in the *Swiss Lakes*, namely, *that the water of the sea and of lakes must receive heat from the earth beneath*. The heat which the sea receives from its bottom depends, as in lakes, on the latitude, and the depth of the water. If the depth of the sea at the equator were only 6658 feet, and supposing the temperature of the earth there to increase with the depth in the same proportion as in the sounding near the *Lake of Geneva*, the temperature of the bottom of the sea would there reach the boiling point; but as the actual temperature at the bottom of the sea at its greatest depths in low latitude, according to Lenz, is $35^{\circ}.96$, we have $212^{\circ} - 3^{\circ}.96 = 208^{\circ}.04$ for the thermometrical expression of the heat which is communicated from the bottom of the sea to the water, and with it brought to the surface. The positive quantity of heat thus brought to the surface obviously depends, as is the case in lakes, on the degree of conductivity of heat of the strata beneath. As the sea in the torrid zone is very commonly far deeper than the above assumed depth of 6658 feet, there must be many places in those regions where the temperature corresponding to the bottom of the sea would be much higher than the boiling point. But, even in the frigid zones, where the mean temperature falls as low as, and even lower, than 32° , much heat may still rise from the bottom of the sea even in moderate depths. The rising of heat from the bottom of the sea may, therefore, be considered as an universal phenomenon, even under the poles, and it will only be found not to take place where the sea in the frigid zones is so shallow, that there is no perceptible difference between the temperature of its bottom and of its surface.

Notwithstanding that the heat which is continually rising in the sea increases in proportion to the depth, yet no perceptible difference in the temperature at the surface can be caused by any variations in the more considerable depths, for in proportion as the quantity of heat which rises from the more considerable depths is greater, so is the quantity of water greater through which it is dispersed. But in shallows this difference must be perceptible; and this is a fact which, it is well known, was observed by Franklin and J. Williams,* and confirmed by later observers, by V. Humboldt† and J. Davy.‡ On approaching land, Williams describes the decrease of temperature as so perceptible, that coasts and shallows were indicated by the thermometer, at distances in which they were not yet visible. He not unfrequently found a decrease in the temperature of the sea of $6^{\circ}.75$ during a sail of three hours, and yet they were out of all danger. In some cases he even observed differences of $11^{\circ}.25$. The more rapidly the depth decreases on approaching a coast, the more rapid is the decrease of temperature. These great differences very clearly shew the influence of the warmer waters rising from below upon the temperature at the surface, and this influence is independent of the seasons, as the experiments also prove. If, on the other hand, Sir H. Davy's § explanation of this phenomenon were right, namely, that the sea becomes cooled at its surface by certain causes, and that in deep places the cooled layers of water are carried to a distance below the surface, whilst in shallows they remain near the surface, this decrease of temperature could only take place when the air is cooler than the surface of the sea. Neither is it to be expected, as Sir H. Davy asserts, that this decrease of temperature should not take place in very high latitudes, where the temperature of the surface of the air is near $27^{\circ}.50$; for in deep places, where the bottom of the sea would always possess a temperature higher than the mean temperature of the air, currents of warmed water must

* Transactions of the American Society, vol. iii. p. 32; and Williams Thermometrical Navigation. Philad. 1790.

† Gilbert's Annal. vol. vii. p. 342.

‡ Philos. Transac. 1817, ii. 275.

§ Journ. of Sc. vol. iii. 1817; and Gilbert's Annal. vol. lxvi. p. 139.

continually rise, and thus impart to the surface a temperature higher than it possesses over shallows. The phenomenon is, therefore, in no way dependent on the latitude, but only on the depth of the sea.

The higher temperature of the surface of the sea in deep places seems also to prove, that only a part of the warmed water which rises from the depths is used in the evaporation of the water at the surface. Now, as the air over the sea partakes of the heat arising from this source, but to a very limited extent, we must conclude, as in the case of lakes, that the mean temperature of the surface of the sea is higher than that of the surrounding atmosphere. And this is shewn to be the case by the observations made four times a-day (at 6 A. M., and 6 P. M., at mid-day, and at midnight) by Peron. He found the mean temperature of the water of the sea at its surface, at a distance from land, between latitudes 49° N. and 45° S., always higher than that of the air immediately in contact with it. According to Humboldt's observations, the ocean is also on an average rather warmer than the air with which it is in contact. The maximum temperature of the seas amounts to between $82^{\circ}.4$ and $84^{\circ}.1$, and the mean temperature of the atmosphere near the equator is only $78^{\circ}.9$ to $80^{\circ}.5$.*

The same was observed by J. Davy,† during his voyage to Ceylon, between latitudes 48° N. and 35° S. He made observations on the temperature of the sea and of the air with the help of two assistants, from the 12th February to the 12th August 1816, every two hours, even during the night, and from them he calculated the mean for each day. Taking the mean of all these observations, which comprises 150 days, we find, that the sea was $1^{\circ}.795$ warmer than the air. Of these 150 days there were only 17° on which the atmosphere gave a mean temperature superior to that of the sea, on five days they were equal, and on 128 days the mean temperature of the air was lower than that of the sea. It may, indeed, with great probability be assumed, that the observations on those seventeen

* Reise, i. 353. See especially the data in the table, p. 352.

† Philosophical Transactions, 1817, ii. p. 275.

and five days were made in shallower places. The greatest excess of the mean temperature of the air over that of the sea in those seventeen days was, however, only $1^{\circ}.3$; whilst, on the other hand, the greatest excess of the mean temperature of the sea over that of the atmosphere, in the 128 days, amounted to $7^{\circ}.87$. Had Dr J. Davy added the depth of the sea, which however would have been attended with many inconveniences to his numerous and valuable observations, it might have been decided with certainty, whether the excess of the mean temperature of the sea over that of the atmosphere, becomes really greater in proportion as the depth increases, and *vice versa*, whether the hypothesis that the mean temperature of the sea in shallows is lower than that of the air, has any foundation. If we take the mean of the thermometrical observations in the sea and in the atmosphere, between latitudes 5° N. and 5° S., we find for the former $79^{\circ}.607$, and for the latter $78^{\circ}.226$, making a difference here also in favour of the former, of $1^{\circ}.454$.

The above observations include the latter half of the winter and a part of the summer in the northern atmosphere, and the whole autumn with the first half of the winter in the southern hemisphere, comprising more of the cold than of the warm seasons. However, if we only take the average of the summer observations in the northern hemisphere, from the 1st to the 12th of August, we find the mean temperature for the sea $79^{\circ}.953$; for the air $78^{\circ}.353$, which even thus gives a difference of $1^{\circ}.575$. The higher mean temperature of the sea as compared with that of the air, seems, therefore, to be by no means confined to the cold season.

Should the water of the sea reach its maximum of density at a certain low degree of temperature, the circumstances would be similar to those above developed relative to lakes in elevated situations. Namely, in high latitudes, where the temperature of the bottom of the sea would be as low as that corresponding to the maximum of density of the sea-water, the sea would neither impart heat to, nor receive heat from, the bottom. In such places there could consequently be no ascending current of water.

If the sea was a motionless mass of water, its temperature in

great depths could never fall below the minimum temperature of the air. The temperatures $46^{\circ}.4$ and $44^{\circ}.5$, observed in great depths in tropical seas, could then not be accounted for, as in such climates the temperature of the air never falls below $65^{\circ}.5$ to 68° . But if inferior currents flow from the poles to the equator, in the manner of the well-known stream which runs from the *Cape* towards the *coasts of Brazil* and the *Gulph of Mexico*, we must no longer be astonished at the low temperatures observed in low latitudes. *

The floating ice-bergs in the Polar Seas, which, according to the corroborative accounts of the whale-fishers and northern navigators, even in a calm, travel southward, seem also in certain seasons to assist in the depression of the temperature of the sea in low latitudes. †

* On these currents see Guy-Lussac, *Annal. de Chim. et de Phys.*, vols. vi. and vii. 1837; Lamarche, *ibid.* vol. v.; and Chladni, in *Gilbert's Annalen*, vol. lxii. p. 133; Barrow, in the *Quart. Rev.* Feb. 1818. No. 35; John Davy, *Edin. Phil. Jour.* vol. xiii., and Von Humboldt's *Reise*. English edition, vol. i. p. 63.

† Will. Scoresby jun., in the *Wernerian Society*, 1815, and Barrow, *Quart. Rev.* as above. In *Davis's Straits* where they are exceedingly numerous, they always travel towards the south, extending without the straits to an almost incredible distance, and are found in great numbers on the shallows about *Newfoundland*, and have been met with in lat. 40° more than 2100 nautical miles from the place of their origin. The whale-fishers are not unfrequently enclosed by them and carried away to S. W. Scoresby relates that ships have often been driven from the usual places for whale-fishing in 78° and 80° N. Lat. and a few degrees of E. Long. in a south-westerly direction into lat. 62° , and longitude 30° W. of *Greenwich*, and have still continued to be borne along. In the Autumn of 1815, the Greenland traders returning from the whale-fishery, brought news that the immeasurable plains of ice which had been amassing for the last 400 years on the coast of *Greenland*, were beginning to break up, and to drift towards the south; in the succeeding years this report was confirmed by several vessels, which, on their return to *England* from the *West Indies*, *North America*, and *Newfoundland*, had met with great fields of ice and lofty icebergs, floating southwards. From latitude $46^{\circ}.5$ to 40° , they continued to be encountered by vessels; indeed, in the summer of 1818, they even proceeded as far as *Cuba* (22° N. Lat.). In the southern hemisphere, floating ice mountains are also met with in extraordinarily low latitudes—in latitude 44° and even 36° . See *Phil. Trans.* for 1830, Part I. p. 117.

But whether this phenomenon is so extensive as to cause, by the melting of such masses of ice, not only a local but a general cooling of the sea in low latitudes, is difficult to determine. 'Tis true navigators have met with masses of ice of several nautical miles in circumference; indeed, one has been seen eight miles in width, and the whole length of which could not be compassed by the eye, and another of such dimensions that a ship required three days to get clear of it, whilst at the same time it rose to a height of 100, 200, and 250 feet above the sea, and must, therefore, have extended to the depth of 450, 900, and 1100 feet below the surface. But, although considerable, what are these masses of ice compared with the enormous quantities of water of the ocean in the temperate and torrid zones? Yet, since several natural philosophers have sought the cause of the cold damp summer of 1816, and a part of 1817, which was so prejudicial and destructive to a great part of *Europe*, in the melting of those enormous masses of ice,* and since, in *Great Britain*, the thermometer was observed to fall whenever the wind blew from the west, it may well be supposed that those masses of ice do actually exert some influence on the depression of temperature in the sea in low latitudes.

As, notwithstanding these causes of a depression of the temperature of the tropical seas, their temperature is still higher than the mean temperature of the air, with which they are in contact; and, as farther, the water of the sea loses some of its heat by evaporation—other causes must cause an elevation of their temperature, which overbalance all these. The water of the sea does indeed receive more heat from the rays of the sun than the air; but it also, on the other hand, loses heat in the night by radiation. It is true we are not able to measure the relative powers of the warming and cooling influences which operate on the surface of the sea; but it is hardly to be supposed that the former could be the most powerful, unless the sea received heat from the earth at its bottom.

* Chladni, in Gilbert's Annal. vol. lxii. p. 132.

PART II.—*Are the observations hitherto made in mines sufficient to determine the law of the increase of temperature towards the centre of the Earth?*

All our former investigations have led us to conclude an increase of temperature towards the centre of the earth; no phenomena, no observations, were contradictory to such an hypothesis; indeed, without its previous admission, many were incapable of explanation. We have now to determine whether this increase of temperature follows any fixed law, and whether that law is the same departing from all points equally distant from the centre of the earth, for example, from the level of the sea. Although it would seem that this inquiry could only be made by means of experiment, by comparing observations actually made, it may yet be deemed not inexpedient, first to consider what causes may influence the internal temperature of the earth, or in general, to determine what modifications the external temperature may operate on that of the interior.

CHAP. XII.—*What influence do the meteoric waters exert on the internal temperature of the Earth?*

In Chap. VII. it has been shewn that the temperature of the meteoric waters has no great influence on that of the crust of the earth through which they flow. But small as this influence is, it will yet be found to be very various in different parts of the earth, according as the strata be more or less pervious to water, or as the waters sink to a greater or less depth. But such variations must naturally disturb any supposed fixed law in the increase of temperature towards the centre of the earth.

The uninterrupted infiltration of the meteoric waters into mines, must cause a general cooling of the surrounding rock; for, admitting the increase of temperature towards the interior of the earth, the mean temperature of those waters must necessarily be lower than that of the mines in their lower workings, where the direct influence of the external heat can no longer be felt. But as we are not yet acquainted with any

other means of ascertaining the increase of temperature towards the interior, than by observations in mines, this difficulty can never be avoided. Reich* justly remarks, that this effect of the atmospheric waters must be greater in old mines than in new ones, although in time we do not doubt it must reach its limit. To this cause, as well as to the sinking of the colder air into the mines, he is inclined to ascribe the less rapid increase of temperature observed in the *Erzgebirge*.

The observations in the *Saxon Erzgebirge* furnish many proofs of the cooling effect produced by the action of the meteoric waters on the rock in mines. Thus, Reich† found from thirty-three monthly observations, that, at a depth of 215 feet in the *Mathusalem* mine, in the *Freyberg* district, the air had the same temperature as the rock, that the seasons of the year seemed to have no effect upon it, but that after continued dry weather the temperature was somewhat elevated, and that it suffered a depression after long continued wet. This depression will of course be greater, if water brought from the surface into the mines, for putting the machinery in motion, should happen to pass near the points of observation.

In a sounding at *Rüdersdorf*, eight leagues from *Berlin*, which has been carried on to a depth of 880 feet from the surface, and 700 feet below the level of the sea, a continued increase of temperature has, indeed, been observed in the greater depths, as well as an uniformity in the temperature of the water which flows out of the sounding pipe, at the bottom of the well or shaft, which extends to the depth of eighty feet; however, from a comparison of the continued observations of more than two years, we find a considerable irregularity in the increase of temperature with the depth. The most rapid increase is observed from 200 to 225 feet deep, where, on the 4th of December 1831, the temperature varied from $56^{\circ}.30$ to $62^{\circ}.37$, giving a difference of 6.07 . This circumstance can hardly be accounted for in any other manner, than by supposing colder springs to exist there, which suddenly cool the warmer waters rising from below.

* P. 133. See page 35.

† P. 58.

The mixing of these springs cannot take place immediately, as the sounding well is lined with a sheet-iron tube to the depth of 621 feet. A later observation gave this sudden increase, between 200 and 250 feet at 5.85; indeed the temperature was found to be generally lower at equal depths at the time of this experiment, than during the former. The highest temperature at the bottom of the well was 74.30.*

Were a well to be sunk on *Teneriffe*, for the sake of thermometrical observation, at less than 4000 feet above the level of the sea, within which limit Von Buch found but slight variations of temperature in the springs, would not such an uniform temperature in the waters issuing forth at such unequal elevations, have some influence on the temperature of the strata situated within those limits?

CHAP. XIII.—*What influence have thermal springs on the temperature of the interior of the earth?*

In Chap. IV. it has been observed, that considerable bodies of water rising with an elevated temperature are capable of influencing the temperature of the soil. This remark holds equally good for strata situated at a greater depth. Were we obliged to confine ourselves to the consideration of those commonly called warm or hot springs, it might be objected that they are a local phenomenon, and ought, therefore, not to be taken into account. But in Chap. I. we have shewn that thermal springs are of very general occurrence; that they are not entirely wanting in any formation; and that in different places they are only more or less frequent, and more or less elevated above the mean temperature of the air, sometimes rising to the surface by natural or artificial artesian wells, and sometimes being held back by impervious strata. How various and innumerable, then, may not be the effects of thermal waters upon the interior strata of the earth?

In the copper mine at *Oatfield*, at a depth of 1392 feet, and

* Poggend. Ann. vol. xxxiii. p. 233. See also vol. xxii. p. 136, and in the "Schriften der Berliner Akademie" for 1831.

72 feet east of the shaft, the temperature was found, in May 1822, to be $79^{\circ}.92$; whilst in an end, situated only 24 feet deeper, 180 feet to the west of the shaft, it was $85^{\circ}.10$. Here the water, which issued in considerable streams from two narrow clefts in the floor of the gallery, but a few feet distant from one another, shewed the unequal temperatures of $81^{\circ}.95$ and $86^{\circ}.45$ *. In the neighbourhood of some tepid springs in the *Churprinz-Friedrich-August* adit, in the *Erzgebirge*, the temperature of the air was exactly $68^{\circ}.0$; and when the waters had acquired an uninterrupted afflux, they soon warmed the rock to such a degree that their temperature remained constant†. How great, then, must be the influence of considerable masses of water of an elevated temperature, such, for instance, as those of *Aix-la-Chapelle*, *Burtscheid*, *Wiesbaden*, *Carlsbad*, &c., on the rock beneath the surface.

Waters which descend into the earth through clefts operate more or less with a cooling effect, and, on the other hand, waters rising from great depths operate more or less with a warming effect, upon the rock.

Innumerable modifications may be caused in the thermometrical circumstances of the interior of the earth by various combinations of cases; we will here mention a few for the sake of example:—

1st, Let EE, Pl. II, Fig. 2, be the bottom of a valley, cut off from communication with the surrounding hills by the impervious strata *d, d, d*, but the soil of which admits of the infiltration of the meteoric waters until they reach those impervious strata. In this case the meteoric waters will only sink into the earth without being able to return to the surface. The soil through which these waters have passed can therefore suffer no alterations of temperature but from without, as all waters which might bring heat from below are intercepted by the impervious strata *d, d, d*.

2d, The contrary case will happen when the impervious strata *d, d, d*, are wanting, and when the waters which sink through the clefts to a certain depth, *t*, (Pl. II, Fig. 3) are forced again to the surface at *h* by hydrostatic pressure.

* Gilbert's *Annal.*, vol. lxxvi. p. 431.

† Reich., p. 153.

3d, Let Fig 4, Pl. II, represent a mountain. The springs in the upper regions will most commonly descend through the sloping channels *ab*, *cd*, *cf*. Here, then, will be an example of case 1st, namely, when the interior strata can only be acted on by the external temperature. As the temperature decreases from below upwards, the strata situated nearer to the foot of the mountain will besides be cooled by the waters which descend from the higher regions. Should any part of the meteoric waters be enabled, by entering extensive fissures in the mountain, to descend far below its foot, and reappear in the plain, it would bring up heat with it to the surface. So that, according as the observations be made in the mountain or in the plain, all other circumstances being alike in both cases, the results must shew an unequal increase of temperature towards the centre of the earth.

If we consider all the cases above investigated, we see that the increase of temperature towards the centre of the earth, even if supposed in itself to follow one fixed law, must be found to be very different, according as the wells in which the observations are made happen to be sunk at the foot of a mountain, or more towards its summit, on an extensive plateau or on the slope of a hill*, whether they be encompassed on all sides by impervious strata, and whether they be immediately surrounded by high mountains or not. What innumerable combinations of these different cases may not be imagined by which the increase of temperature towards the centre of the earth might be influenced?

CHAP. XIV.—*What influence has the air on observations of temperature in mines?*

That this influence must tend materially to disturb the observations is easily to be foreseen. When shafts communicate with adits, or when several shafts of unequal depth are in communication with each other, it is well known that an uninterrupted

* On the influence which the configuration of the surface of the earth has upon the increase of temperature towards its centre, see Chap. XVII.

change of air takes place, the direction of which depends on the external temperature being higher or lower than that of the air in the mine. In the former case the warm air sinks down into the shaft, and the cold air escapes from the adit; in the latter the cold air enters by the adit, whilst the warm air rises out of the shaft. This change of air is not only dependent on the seasons of the year, but on the time of day, and even on the wind, which agitates the air without*.

In the mines of *Cornwall*, a difference of $1^{\circ}.125$ was found at a depth of 1071 feet between the summer and winter observations†. In the auriferous mines of *Pestarena di Macugnana*, in the valley of *Anzasca*, the March and August observations shewed differences of $1^{\circ}.575$ in a depth of 770 feet, which did not entirely disappear until a depth of 1077 feet‡. Among the above-mentioned observations, which have been carried on since 1828 in many of the Prussian mines, holes were bored into the rock in places free from wet and draught, into which the thermometers, surrounded with a non-conductor of heat, were sunk, so that the scales projected sufficiently to enable the observer to read off the degrees without the necessity of withdrawing them. Notwithstanding these precautions, fluctuations were caused in the height of the mercury not only in the upper but also in the lower stations, by the imperfect exclusion of the air from the thermometers. From the table given in Chap. VIII. may be seen how irregular these effects shew themselves at depths of 27 to 63 feet; but even from 145 to 738 feet below the surface differences of 0.562 to 2.25 occur, the latter of which were observed in the greatest depths. The variations of the thermometers in the upper stations corresponded in some cases very regularly with those of the atmosphere, but in others they were totally different. In the latter cases the influence of the air can only have acted very indirectly. The fluctuations in the

* Fox communicates some interesting experiments on the effects of change of air in mines in the Transactions of the Royal Geological Society of *Cornwall*.

† Thomas Lean in the *Annal. de Chim. et de Phys.*, vol. xiii. p. 200.

‡ Schweigger's *Jahrbuch*, vol. lii. p. 268, in note.

lower station seldom corresponded with those in the upper, at one time being altogether different, at another time, although corresponding pretty exactly on the whole, yet each fluctuation being greater than in the upper stations.

In Chap. VIII. it has been remarked, how, during the observations in the *Saxon Erzgebirge*, even thermometers, the bulbs of which were sunk 40 inches into the rock, and that at depths to which heat cannot reasonably be supposed to be communicated through the earth's crust from without, still indicated the influence of the external temperature. Indeed, at the great depth of 1014 feet, at the lowest point of observation, the effect of the air in the mine upon the thermometer, which was increased by the bulb being only situated at a distance of 30 inches from the surface of the rock,* was very great. Here the greatest difference observed during twenty-eight months amounted to $4^{\circ}.77$. The result of the experiments was, that out of 29 different points of observation, situated from 147 to 1014 feet below the surface, 18 were found to give evidence of the more or less considerable influence of the seasons. In one place, at the depth of 687 feet,† during three years, the highest temperature was observed in the middle of the winter, the lowest in the middle or towards the close of summer. The influence of the air could be observed with the greater certainty, in these experiments, as other thermometers, exactly corresponding with those sunk into the rock, were placed, as we have before mentioned, close by them, for observing the temperature of the air.

From all this it follows, that it is extremely difficult, or, in fact, literally speaking, impossible, perfectly to protect the bulbs of the thermometers, buried in the rock, from the influence of the seasons. This would be no inconvenience, if the effect continued, as far as the place of observation, to correspond precisely with the variations of the external temperature, provided the observations were carried on for at least a year. However, it may be supposed, with great probability, and the observations in the *Erzgebirge* seem to favour the supposition,‡ that the effect is more frequently to depress than to raise the tem-

* Reich. p. 36.

† Ibid. p. 31.

‡ Ibid. p. 133.

perature. Unfortunately the extent of this effect is impossible to be determined.

In Chap. VI. we noticed the natural ice-grottos, and, in general, all points which possess a temperature lower than the mean temperature at the surface. We then asserted, with great plausibility, that their number might easily be increased with a little attention. Several philosophers, and, among others, Kupffer*, have wished to explain this phenomenon, by supposing that the cold air which sinks into such caverns in the winter, cannot, by reason of its greater specific gravity, easily re-ascend during the summer, or, at least, that it only gives way for other colder layers. Although this explanation will not suffice in all cases, yet in many it may be admissible. This granted, the observations on the increase of temperature in the earth would suffer material interruptions in places where circumstances are similar to those necessary for the existence of ice-grottos. The above-mentioned observations in the *Erzgebirge*, furnished exemplifications of this fact.

CHAP. XV.—*What influence has climate on the progression of the increase of temperature towards the centre of the Earth?*

Although circumstances of climate may cause differences of several degrees between the mean temperature of places situated in the same latitude, at the same elevation, and at no great distance apart, yet it cannot well be supposed that the influence of such variations would be felt to any great depth in the earth's crust, indeed it could hardly extend beyond the point where the temperature becomes constant. In such a case the progression of the increase of temperature would be found very different in those places.

The climate of a place is influenced by a superabundance of woodland and humidity, and consequently by aridity and barrenness; the former causing cold, and the latter increasing the warmth of the climate; further, by the radiation of heat from heated plateaus, the nature of the soil, the vicinity of glaciers, the accumulation of clouds, and so forth. Thus,

* Poggen. Ann. vol. xvi. p. 262. See also Reich. p. 202.

for example, according to Boussingault, the mean temperature of the valley of *Magdalena* in the *Cordilleras*, situated at a height of more than 600 feet, is the same as at *Carthagena*, on the sea coast. On the other hand, geological peculiarities and proximity to active volcanos do not affect the climate. *Puracé*, *Pasto*, and *Cumbal*, which are commanded by active volcanos, have not a higher mean temperature than *Bogota*, *Santa Rosa de Osos*, and *Puramo de Hervé*, which repose on a perfectly unvolcanic soil.

This subject is treated at greater length in Chapters XVII, and XVIII.

CHAP. XVI.—*The unequal power of conducting heat, possessed by different rocks, causes differences in the progression of the increase of temperature towards the centre of the earth.*

This seems to be particularly striking with respect to metalliferous lodes. Fox* observed in a mine in *Cornwall*, that thermometers sunk into a metalliferous vein, stood in general $2^{\circ}.25$ higher than when placed in holes bored in the rock, particularly in granite. Tin veins usually shewed themselves colder than those which yielded copper. The tin mines of the *Sauberg* at *Ehrenfriedersdorf*† also shew a remarkably low temperature; indeed, it is a prevailing opinion there that stanniferous mountains are colder than others. At *Ehrenfriedersdorf*, the correctness of this opinion could never be questioned, because, in many parts of the mine, ice is at all seasons of the year to be found in considerable quantities. The low temperature of *Heinrichssohle*, in the *Altenberg* district in the *Erzgebirge*, was also supposed to be ascribable to the rocks of tinstone.‡ It may, however, be questioned whether this phenomenon be not a consequence of the dislocated state of the rock, caused by the peculiar method in which it is worked.

* *Annal. de Chim. et de Phys.* vol. xvi. p. 80. — Fox remarks that at equal depths, granite and other hard rocks are, in general, of lower temperature than clay-slate and other soft and porous rocks.

† *Reich.* p. 87 and 107.

‡ *Ibid.* p. 87 and 107.

Arago, with justice, considers this phenomenon of great importance, and remarks, that its further investigation would not only serve to prove the existence of a superior temperature in the interior of rocks and metalliferous veins, but would afford an additional objection to the hypothesis, supported by several philosophers, that the higher temperature in mines is the result of the action of the air upon substances, particularly the pyrites, on the walls of the galleries. To prove that the observation alluded to indicates a more important source of heat in the interior, he adds two mathematical formulæ from Fourier's *Theorie de la Chaleur*, from which it follows that, *cæteris paribus*, the temperature of the mass of a lode which is in contact with the atmosphere is greater, the more easily heat is conveyed into the interior of the mass. Cordier,* in his observations on mines, also mentions the great influence of a metalliferous zone on the subterranean temperature, owing to its superior conductivity of heat.

From the observations on the internal temperature of the earth, carried on in various mining establishments in the Prussian dominions, it has also been found, that the increase of temperature is, in general, much more rapid in coal than in metalliferous mines.† Von Dechen, the publisher of these observations, leaves it undecided whether this greater increase of heat is produced by the decomposition of the pyrites and coal, in which case it would not exist before the opening of the mines,‡ or whether it is a consequence of the locality of the mine. If we take into consideration the difference of the facility with which heat is transmitted by coal and metals, we shall be inclined, agreeably to the observations communicated above, to look upon this as the real cause of the phenomenon. From observations in five coal-mines, the result was, that an increase

* *Mém. de l' Acad. Roy. de Sciences de Paris*, vol. vii. p. 473.

† *Poggend. Annal.* vol. xxii. p. 497 and following.

‡ D' Aubuisson (*Journ. des mines*, vol. xxi. *Annal. de chim. et de phys.* vol. xiii. p. 184. See on the other hand, Fox, in *Gilb. Annal.* vol. lxxvi. p. 427, 442, and 448.) found, in a mine near *Huelgoat* in *Bretagne*, the temperature in the upper works to be $5^{\circ}8$; but at the depth of 230 metres $15^{\circ}8$, and the water vitriolic. See Chap. III.

of temperature of $2^{\circ}.25$ occurred in 123.3 feet, and from observations in two metalliferous mines, the depth corresponding to an increase of $2^{\circ}.25$ was 325.5 feet.

Supposing that the temperature in the upper station of the metalliferous mines, where observations on the increase of temperature were made, should be found $2^{\circ}.92$ higher than in the coal mines, whilst the temperature in the inferior station of both mines would be the same, the depth, corresponding to an increase of $2^{\circ}.25$, would be in the metalliferous mines also 123.3 feet.

It would be difficult to make a correction for this not unimportant influence on the increase of temperature, proceeding from the unequal power of conducting heat of different rocks.

CHAP. XVII.—*Can the increase of Temperature towards the interior of the Earth follow the same law in all parts of the Earth, departing from points all situated in the same level ?*

According to Chap. VIII., the influence of the external temperature under the equator scarcely extends to the depth of twelve inches below the surface of the earth ; whilst in the temperate zones it extends to a depth which has not yet been ascertained, but which in our latitudes, perhaps, amounts to sixty feet. Curves may, therefore, be supposed to be drawn from the equator to the poles ; at the former reaching to within one foot of the surface ; in our latitude lying at a depth of about sixty feet, and extending at the poles to a still greater depth, and thus describing the limit of the influence of the external temperature. A constant regular increase of temperature, dependent only on the interior temperature of the earth, can, therefore, only be supposed to commence below this limit ; the crust of the earth above the line which marks the limit being exposed at the same time to the influence of the external temperature of the air, and of the interior heat of the earth. But under the equator the former influence disappears, and the increase of temperature depends solely upon the interior heat of the earth. In higher latitudes, on the other hand, both influences are found to operate. This we find by observations on the temperature of those springs which have their origin within this limit ; namely, those springs observed by me, and

cited in Chap. XVIII, No. 1, 8, 12, and 14, which shew yearly variations of temperature, but have yet a higher mean temperature than that of the place where they rise. In general, all thermal springs which shew yearly variations of temperature, may be considered as proofs of this assertion.

It must be remembered that the limit of the influence of the external temperature is absolute, but not so that of the internal. According as the depth below the surface be greater or less, so will it require a longer or shorter time after the minimum temperature of the air, before the temperature of the variable crusts of the earth will begin constantly to increase, until the temperature of the air reach its maximum. And according as the depth below the surface be greater or less, so will it require a longer or shorter time after that maximum, before the temperature will begin to decrease again, which will continue until the return of the former period. Thus, during the first half year, there will be a transmission of heat from the surface towards the interior; and during the second half-year, on the contrary, from the interior towards the surface. This oscillation during these two periods can, of course, only take place within the variable crust of the earth. Should ever the period from the minimum to the maximum increase to the double, the depth to which the external temperature penetrates would also increase almost to the double. That, in fact, the maximum and minimum temperatures of the air do not coincide with those of the soil; but that the yearly extremes of the latter occur, at the deepest points of the variable crust of the earth, according to the observations on the temperature of springs, about three months later than those of the former, is evidently a consequence of the slow transmission of the heat through the strata of earth and rocks. This circumstance, however, has no effect upon our considerations.

But how is it with the heat proceeding from the interior? Here we have no changes of the seasons. Here there is always an excess of heat in the interior, and a smaller quantity in the variable parts of the earth's crust. The direction of the communication of the heat must, therefore, always be the same; namely, from the interior towards the surface. In the part of the earth's crust, subject to variations of temperature, there is,

consequently, a transmission of heat during one half of the year from below towards the surface; and during the other half, from the surface towards the centre of the earth; but from the interior it is emitted constantly from the centre towards the surface. That the latter is actually the case, is very clearly proved by the above-mentioned springs, which participate in the variations of temperature in the outer crust, but yet are thermal.

To find the law of the increase of temperature for a given place, entirely free from all external influence, the depth must always be first determined by observations, to which the immediate external influences penetrate. In Chap. VIII. we have already seen that this is a difficult problem.

If the external causes which have an influence on the temperature of the earth in a certain district, penetrate to a certain depth t feet; then, all other circumstances being the same, this depth would be the same in the mountains of that district as in the plains. Let us suppose the district only to be of such an extent, that t have the same value at every point of it; the limit of the external influences would then be parallel to the form of the surface, running horizontally beneath the plains, and rising under the mountains.

Supposing the decrease of temperature to depart from the centre of the earth, or from any spheroid concentric with the surface of the earth; it is immaterial what the temperature of the centre or of the nucleus bounded by that spheroid may be; this decrease of temperature, all other circumstances being the same, cannot proceed according to the same law towards all points of the earth's surface in concentric spheroids. For in that case there must be the same temperature at all points of the spheroid which forms the limits of the influence of the external temperature, whether under the equator, or under the poles. The decrease of temperature from the interior of the earth towards its surface must, therefore, follow different laws in different latitudes; that is to say, the temperature must increase more slowly in proportion to the depth, under the equator, than at the poles.

If we imagine curves drawn from the equator towards the poles, all points of which having the mean temperature at the

equator, or $81^{\circ}.50$, they will touch the surface at the equator, but will diverge from it as the latitude becomes higher, and at the poles they will dip deepest into the earth.* If, for example, we draw such a line in the meridian of *Cornwall*, it will there dip to a depth of 144 fathoms; for at this depth, according to Fox, the waters in the mines have the mean temperature of the equator. All these curves in the different meridians form a spheroid, which is somewhat more flattened than the surface of the earth. We may denominate these curves of equal temperature *subterranean Isothermal* or *chthonisothermal lines*, from $\chi\theta\omega\nu$, the earth. It is easy to be perceived, that these curves will bend sometimes upwards and sometimes downwards. Supposing the earth once to have had a higher temperature, equal throughout its surface, whether on mountains or in valleys; then the increase of temperature towards the centre, all other circumstances being the same, and supposing the atmosphere at any place to have had the same temperature at all heights, would, after the cooling down of the earth from the surface towards the centre, have followed the same progression from all points of its surface. But as the temperature of the air decreases in proportion to the height above the surface of the earth, the different points where the increase of temperature is the same, cannot, even within a small space, lie equally distant from the curved surface of the earth. If we apply this to an uneven portion of the surface of the globe, of so small an extent, that the decrease of temperature caused by the difference of latitude is not perceptible; then the curve ABC, Fig. 6, Plate II, parallel to the surface of the earth, will not have an equal temperature at every point. For, as the temperature of the air is lower at D than at E, the curve of equal temperatures must be different from ABC, and must pass through a point F, lying deeper, or further from the surface than B.†

* If the mean temperature at the North Pole is, as Von Buch assumes, $= 19^{\circ}.85$, and if the temperature there increases at the same rate as in the temperate zone, the curve of $81^{\circ}.50$ would fall at the North Pole to a depth of 3151 feet.

† In former observations on the temperature in mines, only the vertical depth in which a certain increase of temperature has been discovered, is given, without taking into consideration, that observations from E to A must

From this it follows, that a chthonisothermal line of any temperature, which was under a small district parallel to the surface, cannot continue its course under a neighbouring mountain, either parallel to the external configuration of the mountain, or in the continuation of its former direction, but must curve upwards as in the figure.

It might be for a moment supposed that the decrease of temperature from the base of a mountain to its summit, would follow the same law as that which takes place in the same elevation in the atmosphere. But in that case we could never find a higher temperature in the interior of a mountain than at its basis; which, however, is contradicted by the observations made in some mines situated in very high mountains in *America*.

The workmen in the mines of *Guanaxuato* in *Mexico* ($21^{\circ}15'$ north latitude) find themselves at a depth of 1607 feet in a temperature of $98^{\circ}.15'$. This is about $15^{\circ}.75'$ higher than the temperature of the equator at the level of the sea, and yet this point lies at a height of 4617 feet above the sea*. Boussingault† found the temperature of the soil near the *Hacienda del Rodeo*, at an elevation of 4128 feet, to be 68° ; and Von Humboldt, at an elevation of about 11,200 feet above the sea, in the *Mina del Purgatorio*, in *Peru*, and in about the same latitude, found a temperature of $67^{\circ}.28'$. The chthonisothermal line of 68° , therefore, rises 7072 feet between these localities.

The rising of the chthonisothermal lines in mountains of less considerable elevation is also proved in our quarter of the globe. In the bore at *Pregny*, near *Geneva*, (Chap. XIX.), a temperature of $63^{\circ}.05'$ was found at a depth of 680 feet below the surface, and 511 feet above the level of the sea. De Saussure‡ found the same temperature in the mine at *Bex*, 677 feet below the surface, and about 2300 feet above the sea. Thus the chthonisothermal line of $63^{\circ}.05'$ rises about 1789 feet between

give a very different result from those made between D and B. This point was first mentioned in Von Dechen's thermometrical observations in various *Prussian* mines.

* Von Humboldt in Gilbert's *Annal.* lxxvi. p. 450.

† *Annal. de Chim. and de Phys.*, vol. liii. p. 245.

‡ *Voyages dans les Alpes*, § 1088.

Geneva and Ber. *London*, situated in latitude $51^{\circ}.40'$ north, lies 14 feet above the sea, and the mean temperature of the soil is $51^{\circ}.01$. The eighth gallery in the *Churprinz-Friedrich-August, Erbstore*, near *Freyberg*, in nearly the same latitude, ($50^{\circ}.55'$), lies 41 feet above the sea, and 926 feet below the surface, and has a mean temperature, according to the average of three years' observations, of $60^{\circ}.28''$. Between these two points, therefore, which are situated in nearly the same latitude and elevation above the sea, there is a difference of temperature of $9^{\circ}.27'$. The point in this *Freyberg* mine, at which the temperature of the earth is the same as that of the soil at *London*, was found to be 731 feet above the sea. So that a chthonisothermal line of $51^{\circ}.01$, supposed to be drawn from *London* to the *Erzgebirge*, would, at the former of these places, almost reach the level of the sea, but in the latter it would rise to a height of 731 feet above it.

Even many springs (Chap. XVIII) shew that the chthonisothermal lines suffer an elevation in passing under elevated parts of the earth's surface. Thus No. 1 and No. 8 shew nearly the same temperature. And as the latter lies 134 feet higher than the former, the chthonisothermal of $51^{\circ}.35$ must there rise 134 feet within a distance of about two leagues.

The rising of the chthonisothermal lines under mountains is, therefore, a very general phenomenon. Their inclination to the horizon is determined by the inclination of the side of the mountain, by the decrease of the temperature of the air or of the surface of the earth with the increase of elevation, and by the increase of temperature towards the centre of the earth. Let AB, Pl. II, Fig. 7, be the sloping side of a mountain, and let the mean temperature at A and D = t° , and at B = $t^{\circ} - 1^{\circ}$: then BD is the depth in which the temperature increases 1° , and CB = AE the height in which it decreases 1° ; we have therefore:

$$\begin{aligned}\tan \alpha &= \tan \text{BAC} \cdot \frac{\text{DC}}{\text{BC}} \\ &= \tan \text{BAC} \cdot \frac{\text{BC} - \text{BD}}{\text{BC}}\end{aligned}$$

When the depth below the surface, in which the temperature

* Reich., p. 47.

increases a certain number of degrees, is required, it may be measured either in a direction perpendicular to the horizon or to the surface of the earth at that place. In an horizontal plain these two directions become identical, and therefore it is unnecessary to make any distinction. This is not the case in mountains. A simple consideration shews, however, that the direction in which the increase of temperature in mountains must be measured is perpendicular to the slope of the hill, and not perpendicular to the horizon. If we suppose, for example, that a mountain forms a perpendicular precipice BC, Fig. 7, it is clear that the increase of temperature, caused by heat in the interior of the earth, cannot proceed in a vertical direction; for BC is a part of the earth's surface, and the surface is under the immediate influence of the temperature of the air. From B to C, therefore, there can be only such an increase of temperature as takes place in the same direction in the atmosphere*.

That which is so evident in a mountain having a perpendicular side must also take place in mountains the slope of which is more or less inclined to the horizon. The increase of temperature in mountains can, therefore, only be measured in a direction perpendicular to their surface. So that in a conical mountain ABD, Pl. II, Fig. 8, we can only measure the increase of temperature from the exterior to any point F in the interior of the mountain, in the direction EF or GF. But since the increase of temperature towards the centre of the earth has hitherto always been measured in a direction perpendicular to the horizon, it remains to be determined in what ratio are the lines EF and BF.

Let the mean temperature at B = t° , at F = $t^{\circ} + 1^{\circ}$, at E = $t^{\circ} + x^{\circ}$; and let the angle BAC = a ; let the temperature be supposed to increase 1° , in every n feet, in a direction perpendicular to the slope of the mountain; and suppose the tem-

* If the increase of temperature in mountains proceeded in a direction perpendicular to the horizon, and at the rate of $2^{\circ}.25$ in every 115 feet, we should have an increase of temperature of $191^{\circ}.25$ from the summit to the foot of the celebrated tremendous precipice of *Caravalleda*, which has an almost perpendicular height of 9800 feet; so that at the foot there would be a temperature of 248° , as Von Humboldt found $56^{\circ}.75$ at the top at a time when the actual temperature in the *Guayra*, on the sea coast, was only $81^{\circ}.50$. See Gilbert's *Annal.*, vol xxiv. p. 25.

perature of the atmosphere, or of the surface of the earth, to decrease 1° R. ($= 2^{\circ}.25$ F.) for every additional m feet in height, then we shall have

$$BH = mx$$

$$EF = (t^{\circ} + 1^{\circ} - t^{\circ} - x^{\circ})n = (1 - x)n$$

but further,

$$BE = \frac{BH}{\sin a}$$

$$EF = BE \cotang a$$

$$= BH \frac{\cotang a}{\sin a}$$

Substituting the above values of BH and EF , we find

$$(1 - x)n = mx \frac{\cotang a}{\sin a}$$

and from this we obtain

$$\begin{aligned} x &= \frac{1}{\frac{m \cotang a}{n \sin a} + 1} \\ &= \frac{n \sin a}{m \cotang a + n \sin a} \end{aligned}$$

We have, therefore,

$$BH = \frac{mn \sin a}{m \cotang a + n \sin a}$$

$$EF = n - \frac{n^2 \sin a}{m \cotang a + n \sin a}$$

$$= \frac{mn \cotang a}{m \cotang a + n \sin a}$$

$$BF = \frac{mn \cotang a}{\cos a (m \cotang a + n \sin a)}$$

Example: let

$$a = 30^{\circ}$$

$$n = 115 \text{ feet}$$

$$m = 677 \text{ feet}$$

then we shall have

$$x = 0.047$$

$$BH = 31.65 \text{ feet}$$

$$EF = 109.62 \text{ feet}$$

$$BF = 126.62 \text{ feet}$$

Thus, if in plains an increase of temperature of $2^{\circ}.25$ be found at a depth of 115 feet, the same increase will not be found till a depth of 126.62 feet, in a vertical direction from the summit of a

conical mountain, whose sides make an angle of 30° with the horizon. The relations will be the same, if from B (Pl. II. Fig. 9.) there extend a large plateau. The increase of temperature towards the interior of the earth will still advance more slowly in a vertical direction from B than in plains. But at a certain distance from B at K, the same increase of temperature will be found as in plains. In order to find the point K, we will suppose the temperature of the earth's crust at I to be y° higher than at B. If, further, the temperature at L be 1° higher than at K or at B, we shall have

$$IL = (1 - y)n$$

$$KL = n$$

$$KN = my$$

but since

$$IN = IL \sin a = (1 - y)n \sin a$$

$$LN = IL \cos a = (1 - y)n \cos a$$

$$KL - LN = KN$$

by substituting the values of these lines, we shall have

$$n - (1 - y)n \cos a = my$$

from which we get

$$y = \frac{n(1 - \cos a)}{m - n \cos a}$$

Substituting this value of y , we find

$$IL = n - \frac{n^2(1 - \cos a)}{m - n \cos a} = \frac{mn - n^2}{m - n \cos a}$$

$$IN = \frac{(mn - n^2) \sin a}{m - n \cos a}$$

$$KN = \frac{mn(1 - \cos a)}{m - n \cos a}$$

If IB and NK be prolonged till they meet in O, we shall have

$$NO = IN \tan a = \frac{(mn - n^2) \sin a \tan a}{m - n \cos a}$$

$$OK = NO - KN$$

$$= \frac{(mn - n^2) \sin a \tan a - mn(1 - \cos a)}{m - n \cos a}$$

$$BK = OK \cot a$$

$$= \frac{(mn - n^2) \sin a - mn(1 - \cos a) \cot a}{m - n \cos a}$$

and if we give to a , n , and m , the same values as in the above example, we shall find

$$y = 0^{\circ}.0267$$

$$BK = 24.7 \text{ feet}$$

Under these circumstances, then, the increase of temperature towards the centre of the earth, would be found the same at K, at a distance of 247 feet from the point B, on the plateau BM, as in plains.

If the plateau BM be not horizontal, the value of BK may be easily deduced from the above formula. If BM rise, for example, at an angle of b from the horizon, the angle a is changed into $a - b$. If, on the contrary, BM fall at an angle of b , the angle a is changed into $a + b$. In the equation of BK, therefore, instead of a we must put, in the former case $a - b$, in the latter $a + b$.

The formulæ calculated above, enable us to describe the curves of the chthonisothermal lines in all mountains. It is evident, that they must form very irregular curves in mountains of irregular shapes. If a BCf (Pl. II. Fig. 10.) represent the vertical section of a mountain, the sides of which have an inclination of 30° and 72° , and having a horizontal plateau on its summit; and if, further, its height be 677 feet, so that, as it is above supposed, the temperature decrease $2^{\circ}.25$ from its foot to its summit, then the chthonisothermal line having the mean temperature of the foot of the mountain, will take the direction of the lines $abcdef$. The numbers 127, 115, and 249, represent the depths in feet, in which the temperature increases $2^{\circ}.25$, and 25 and 69 feet are the distances from B and C, at which the normal increase of temperature of $2^{\circ}.25$ in 115 feet will begin to prevail on the plateau. The dimensions in the figure are drawn exactly according to a scale.

Among all the observations which have hitherto been made for the sake of discovering, in a direct manner, the increase of temperature towards the interior of the earth, I only know one which has been made in an almost horizontal direction. It is that one which was made by Boussingault* in the metaliferous mountains of *Marmato*. This mountain is so steep

* Annal. de Chim. and de Phys., vol. liii., p. 240.

that it may almost be called an enormous wall of porphyritic syenite. Several adits enter it at different heights. At the mouth of one of these adits, 4494 feet above the level of the sea, the mean temperature is $68^{\circ}.0$, and the temperature increases towards the interior of the mountain at the rate of $2^{\circ}.25$ in about 127.5 feet. Boussingault says *about*, because it is not uniform, but varies according to the thickness of the rock above the adit, or, which is the same thing, according to the form of the surface of the mountain. The miners work in an atmosphere, the temperature of which is nearly equal to that on the sea-coast.

This fact, together with the remark, that the increase of temperature is regulated by the thickness of the rock above the adit, proves very clearly that the increase of temperature can only be measured perpendicularly to the surface of the earth. It is singular that the above result accords within a foot with the increase of temperature found in a vertical direction, in the *Erzgebirge* (see Chap. XIX). Supposing the side of the mountains of *Marmato* to be quite perpendicular, and that the temperature of the surface there decreases $2^{\circ}.25$ in 690 feet additional elevation (see Chap. XVIII.), the chthonisothermal line, having the mean temperature of the foot of the mountain, would then rise at an angle of $79^{\circ}.32$ with the horizon. This is, in general, about the maximum angle at which chthonisothermal lines can rise in mountains having a perpendicular ascent.

We must not leave the question undecided, whether the value of n , taken in a direction perpendicular to the surface of the earth, is always the same; all other circumstances remaining the same, whether in plains, in deep valleys, surrounded with high mountains, or in mountains. If the nucleus of the earth possesses a certain quantity of heat, which is radiated towards all points of its surface, it might be expected that this distribution of the heat would be unequal at different points, according as they were situated on lofty projections or in deep hollows; so that in the mountains, at the greatest distance from the centre of heat, the increase of temperature would proceed more slowly than under plains and valleys. But however probable it may be, that a certain portion of the heat which spreads to the more distant points, suffers a slower decrease from the centre towards

the surface; yet it must, on the other hand, not be forgotten that the highest mountains are almost nothing in comparison with the diameter of the earth, and that where heat is forced to extend to greater distances from its source, a communication of heat takes place from all sides.

In the same manner as the chthonisothermal lines bend upwards in mountains, so will they, on the contrary, curve downwards under the sea, under lakes, and under glaciers.* The bottom of the sea, between a certain latitude in the frigid zones and the equator, has every where a lower temperature than it should have in consideration of its latitude alone. If, therefore, we draw a chthonisothermal line of t' , from a continent or an island, towards the bottom of the sea, since the temperature is there more or less under t° , the line must sink more or less below it. All other circumstances being the same, such a chthonisothermal line will suffer a greater depression, the nearer we approach the equator, and consequently the greater the value of t° . The same thing takes place under lakes and glaciers; and such a chthonisothermal line will sink deeper under these, *ceteris paribus*, the nearer they are situated to the equator, and the less their elevation above the sea. As, for example, according to Chap. XI., the temperature of the sea in its depth, even in the torrid zone, does not exceed 32° , the chthonisothermal of $81^\circ.50$ (the mean temperature on the equator) will sink to a depth of about 2500 feet beneath the bottom of the sea, provided the value of n be the same under the sea as under plains. Now if we take the highest mountain on the earth as the measure of the greatest depth of the sea, we should have two points under the equator of equal temperature, $= 81^\circ.50$, the one touching the surface of the earth on terra firma, the other situated 26,500 feet below it. Similar differences will occur, though of smaller extent, between two points of equal temperature, one of which is situated on the banks of a lake, or near a glacier, the other beneath the bottom of the lake, or under the glacier.

* That which holds good for glaciers is also applicable to accumulations of snow and ice in narrow valleys, only in a much less degree. See Von Buch in Gilbert's Annal., vol. xli., p. 2.

If the line DA, Pl. II. Fig. 11. represent a part of the surface of the earth on the sea-coast or on the banks of a lake; DAC the angle formed by the line AC, which runs along the bottom of the sea or lake to its deepest point C, and the line AD; and if, further, the mean temperature at D or $A = t^\circ$, at $C = t^\circ - p^\circ$, at $B = t^\circ - p^\circ + 1^\circ$, and consequently $BC = n$; we shall have

$$DAB = DAC - BAC$$

and BC being perpendicular to AC we find

$$\sin BAC = \frac{BC}{AB} = \frac{n}{AB}.$$

Thus, then, we find the inclination of the line AB, the chthonisothermal of t° , to the surface of the shore of the sea or lake.*

What will be the value of n , beneath the bottom of the sea, of lakes and of glaciers? As direct observations are here entirely wanting, we must be satisfied with determining, by general considerations, what will be the ratio of this value to that which has hitherto been found beneath that part of the earth's surface, which is not covered with water or ice.

Let us imagine to ourselves a point at the bottom of a lake, which, if the lake were not filled with water, but with the solid substance of the earth, would have a temperature t° , a temperature higher than $38^\circ.75$: then, if by any revolution of nature the solid matter above this point were suddenly to be removed and replaced by fresh water, this point would assume the temperature of the water. But this temperature would, after some time, change to that at which water assumes its greatest density, provided the temperature of the air at the surface had, during that time, been reduced so low, namely, to $38^\circ.75$ (Chap. XI). Under all these suppositions the said point would, therefore, have been reduced in temperature from t° to $38^\circ.75$. But since the difference of temperature between this point and n feet below

* The deepest point of the bore at *Pregny* near *Geneva* is 680 feet below the surface of the earth, and is nearly on the same level with the bottom of the lake, near *Geneva*. The temperature of this point is $63^\circ.05$, that of the lake in its depths, and consequently, also of its bottom, is, according to De la Beche, 43° . If the temperature increases beneath the bottom of the lake at the same rate as in the bore, the point beneath the bottom of the lake, which has a temperature of $63^\circ.05$, must be situated 979 feet lower than the lowest point of the bore.

it was originally $t^{\circ} + 2^{\circ}.25 - t^{\circ} = 2^{\circ}.25$, after it became covered with water this difference must have risen to $t^{\circ} + 2^{\circ}.25 - 38^{\circ}.75 = t^{\circ} - 36^{\circ}.50$. So that the higher the original value of t° was, the greater will be the difference after the filling up of the lake with water. Now, as in general, a difference of temperature of $2^{\circ}.25$ occurs in n feet, a greater difference of temperature than $2^{\circ}.25$ for the same depth cannot long exist. The cooling of the bottom of the lake, which at the moment of its filling with water is only superficial, will soon extend to a greater depth. But however deep this cooling may extend, yet there must be a point at which it becomes equal to nothing, or at least imperceptible. The increase of temperature beneath lakes, must, therefore, follow a more rapid progression, that is to say, the value of n must there be smaller than under the solid earth.

The same will be the case under seas and glaciers: under the sea, where it has a great depth, even in high latitudes, provided only that the temperature of the bottom of the sea do not reach that degree which it would have, were it completely filled up with the solid matter of the earth, and under glaciers also, only so long as the original mean temperature of the soil beneath them is not reduced to 32° . (Chap. IX). Under the deepest parts of the sea, the value of n will be considerably diminished; for, according to Chap. XI. if the depth of the sea, under the equator, for example, is equal to 6658 feet, the original temperature of the bottom of the sea would almost reach the boiling point of water. The reduction of this to $35^{\circ}.96$, the lowest temperature observed in the depths of the sea in low latitudes, would consequently require a very considerably more rapid increase of temperature towards the interior.

As the solid masses of our globe are very bad conductors of heat, the reduction of temperature consequent on the creation of a lake, or the filling up of an alpine valley with a glacier, must certainly ensue very slowly. We may obtain a measure for the time necessary for the progress of this reduction of temperature towards the interior, from the time which the temperature of the air, as it goes through the successive changes of the seasons, requires in the temperate zones, to penetrate to a certain depth into the crust of the earth. From the observations communicated in Chap. VIII. and XVIII, we find that at a depth of

four to six feet the maxima and minima follow about a month later than in the air. In the shafts in which I am making thermometrical observations at various depths, the maxima and minima at a depth of 24 feet follow more than two months after those of the air. The observations in the *Erzgebirge* also shew, in general, that the maxima and minima take place later, the deeper the points of observation lie; however, there is no perfect regularity in their succession, which is, no doubt, caused by the distributing influence of the external temperature. The springs also, which shew the smallest variations in their temperature, reach their maxima and minima of temperature about three months after those of the air. But as the depths from which they rise are unknown, no positive conclusion can be drawn from them, as to the length of time necessary for the temperature of the air to penetrate to a certain depth. Thermometrical observations, extending to the greatest depths, to which the external influences penetrate, will, at a future time, furnish us with accurate data, from which to determine the time necessary for the spreading of heat into the interior of the earth. Till then we can always assume, that about three months must elapse before the temperature at the surface can reach a depth of about 60 feet. But this depth does not only depend on the conductivity of heat of the strata of rocks and earth; but also on the difference of temperature. For the greater the change of temperature which a point of the earth suffers, the more quickly will this change of temperature be communicated to the interior. The greater the reduction of temperature, therefore (to apply this to the example in question), which the bottom of a lake at the moment of its creation, or a valley which becomes filled up with a glacier, suffers; the more rapidly will the reduction of temperature, all other circumstances being the same, travel into the interior. This is perfectly analogous to the effect of latitude on the depth, to which the external temperature penetrates into the earth. In high latitudes, where the yearly variations of temperature are greater than in low ones, the external temperature also penetrates more rapidly than in low latitudes; because the point where the temperature first becomes constant lies deeper in the former than in the latter. But that which is effected by

a greater yearly variation of temperature, must also be effected by a greater instantaneous change of temperature.

Those seas and lakes, which have a great depth immediately near shore, will produce a depression of temperature on the shore, in consequence of the low temperature at their bottom. So that, if the mean temperature at a certain distance from the lake or sea, where its cooling influence can no longer be felt, be t° , the chthonisothermal of t° will bend downwards on approaching the sea or lake. It would be interesting to discover the mean temperature of the earth on the shores of deep lakes or seas, and at various distances from them, in order by that means to ascertain to what distance their cooling influence extends, and to determine the consequent curves of the chthonisothermal lines. For want of such observations, continued as they should be for at least a year, I made some solitary observations on the temperature of the earth, at a depth of one foot, between the lakes of *Thun* and *Brienzen*, on the 1st Sept. 1835, from which I obtained the following results:—

Lake of <i>Thun</i> , at its surface, close to the shore, near <i>Neuhaus</i> ,	70.47
———— at the bottom, at a depth of 15 inches,	64.85
The <i>Aar</i> , where it falls into the lake,	66.0
The soil, temperature of the sand at the bottom of the lake, at the same spot,	58.10*
The soil, at another spot near the shore, where the lake is very shallow,	57.65, ⊙
	56.41 Sh.
	Mean 57.02
The soil, 230 paces from the lake towards <i>Unterseen</i> ,	61.92 ⊙
	57.20 Sh.
	Mean 59.56
———— half-way between the lake and <i>Unterseen</i> ,	62.37 ⊙
	57.42 Sh.
	Mean 59.89
———— at <i>Unterseen</i>	61.47 ⊙
	58.55 Sh.
	Mean 60.01

* The observations marked ⊙ were made in many places exposed to the rays of the sun; those marked Sh., on the other hand, were made in the shade on the north side of houses, walls, and so forth.

The soil near <i>Interlaken</i> towards the lake of <i>Brienx</i> ,	63.05 °
	56.30 Sh.
Mean	59.67
— 40 paces from the lake of <i>Brienx</i> ,	58.55 °
— 8 paces from the lake of <i>Brienx</i> ,	55.40 Sh.
Mean	56.97

Thus, the temperature of the surface of the earth decreased 2°.92 from *Unterseen* towards the lake of *Thun*, as well as towards the lake of *Brienx*. But where the observations were made on the shore of the lakes, they become gradually deeper and deeper; and the deepest points in both lakes are at a great distance from the shore.

The following observations also prove the cooling influence of the bottoms of lakes on their banks.

Near <i>Därigen</i> , on the lake of <i>Thun</i> ,	57.87 °
At <i>Aeschi</i> on the <i>Niesen</i> , 930 feet above the lake of <i>Thun</i> .	57.20 °
	56.05 Sh.
Mean	56.62

At the lake of <i>Brienx</i> , near the <i>Giesbach</i> , and not far from the place where the lake is deepest,	53.37 °
1578 feet above the lake of <i>Brienx</i> , higher up than the waterfalls,	53.37 Sh.

Notwithstanding the immense difference of elevation between these two points, the temperature of the soil was the same. But I do not mean to maintain that there is no decrease of temperature between these two points. The mean temperature of the point situated 1578 feet above the lake of *Brienx* would certainly be found lower than that on the bank of the lake. At the time that I made those solitary observations, the temperature of the soil at a depth of 1 foot was above the mean; but more so at the higher point than near the lake, because the yearly maximum occurs later in higher regions than in valleys. Hence the equality of the temperatures observed at the two points, notwithstanding their considerable difference of elevation. However, it may almost with certainty be assumed, that, owing to the cooling influence of the bottom of the lake on the lower point, a smaller decrease of temperature would be found between these two points, than in places where no such cooling influences exist.

In the same manner, as lakes and seas cause a depression of temperature in their immediate environs, so do also the glaciers. To prove this, I also made some observations near the lower glacier of *Grindelwald*, at a depth of 1 foot,* on the 26th August 1835, the results of which were as follows:—

Close to the glacier,	+ 36.50
On the banks of the glacier-stream, where the first vegetation, grass and alder-trees, begins,	46.62
100 paces from the same,	51.12
200 paces from the same, near the bridge,	51.12
460 paces from the same, beyond the bridge,	52.47
720 paces from the same, where the first potatoes are cultivated, and where the first maple and cherry trees stand,	51.8†
12.86 paces from the banks of the glacier-stream, the <i>Schwarze Lutschine</i> , near the bridge,	49.10‡
Only 8 paces from the same,	55.40
1788 paces from the glacier, near <i>Grindelwald</i> , where the first wheat is grown,	56.75

Quite close to the glacier the temperature of the soil is considerably modified by that of the air. Thus at the same spot, near the glacier, where the temperature of the soil, on the 26th August, the weather being cold and damp, was $46^{\circ}.62$, rose to $47^{\circ}.97$ on the 28th, when the weather had become fine and warmer, and on the 7th September, up to which time the days had continued warm, I found it as high as $49^{\circ}.32$. At *Grindelwald*, on the contrary, at a distance from the glacier, the temperature decreased from the 26th August to the 7th September, $32^{\circ}.67$, which was exactly correspondent to the advance of the season.

A chthonisothermal line of t° , at such a distance from the glacier that its cooling influence on the soil could no longer be felt, would, therefore, bend downwards on approaching the glacier.

* The first observation only excepted, which, on account of the quantity of stones, could only be made at a depth of 6 inches.

† This somewhat lower temperature probably proceeds from a copious brook which runs down from the *Mettenberg*, at the very spot where the observation was made, with a temperature of $43^{\circ}.81$.

‡ Here we see the cooling influence of the *Schwarze Lutschine* whose temperature is only $41^{\circ}.00$, but which disappears, however, as the succeeding observations shews, at a distance of 8 paces. On the 28th December Mr Ziegler found the temperature of the *Schwarze Lutschine*, under the ice, to be 32.22 .

10th of November, as was the case in my observations near *Bonn*, communicated in Chap. XVIII., we might by interpolation in the above observations obtain a mean for each of the three points, which would be as follows:—

Glacier.	Mettenberg.	Garden.
34°.90.	40°.28.	44°.84.*

But should they fall, according to my observation on the *Löwenburg*, on the 24th November, the interpolation would give for the mean temperatures—

At the Glacier.	Mettenberg.	In Garden.
33°.91.	38°.30.	42°.68.*

In the former case the increase of the mean temperature from the glacier to the foot of the *Mettenberg*, would be 37°.37; and from thence to *Grindelwald* 36°.56; in all 41°.94. In the latter case the increase would be, from the first to the second point, 4°.39, and from the second to the third, 4°.39, making in all 8°.78. Taking the mean of these two results, we find that the increase of temperature from the glacier to *Grindelwald*, a distance of about 4500 feet, is 9°.36. If, then, the increase of temperature towards the interior of the earth, advances 2°.25 in 115 feet at the glacier; the chthonisothermal of 43°.77, which, at *Grindelwald*, touches the surface, will pass at a depth of 478 feet under that point of the glacier, and the chthonisothermal of 39°.29, which touches the surface at the foot of the *Mettenberg*, will dip 250 below the same point. As the second point of observation, at the foot of the *Mettenberg*, is situated about 1800 feet, and the third at *Grindelwald*, about 4500 feet distant from the glacier; and as, farther, the two first places are nearly on the same level, but *Grindelwald* 248 feet higher than the lower end of the glacier; those chthonisothermals must form an angle with the horizon of about 9°.10' to 10°.27'.

These relations are illustrated in the diagram, Fig. 5, Plate 2, where *c* is the point of observation of the glacier, *d* the point of

* Heer found the mean temperature of the air at *Matt*, in the canton *Glarus*, 2560 feet above the level of the sea, between August 1831 and August 1832, to be 43°.85. (Fröbel and Heer, Mittheilungen aus dem Gebiete der theoret. Erdkunde. Zurich. 1836. P. 492.) As *Grindelwald* lies 677 feet higher than *Matt*, and in the vicinity of the glacier, 42°.68 is probably nearer the truth than 44°.84.

observation at the foot of the Mettenberg, *b* the point of observation in the Grindelwald, *ab* the horizontal line, Fig. *cdb* profile from the glacier of the Grindelwald, *ed* the chthonisothermal line of $39^{\circ}.31$ Fahr., and *fgb* the chthonisothermal line of $43^{\circ}.77$ Fahr.

From these observations it is evident, that the cooling influence of glaciers on the soil in their vicinity is not felt to any great distance; but that it is soon counteracted by the heat of the air. This accounts for the remark so often met with in descriptions of travels, that flowers and strawberries may be gathered within sight, nay in the immediate neighbourhood, of the glaciers.

The mean temperature at the glaciers is about the same as that of *Barnaul*, in Asiatic *Russia*, 53° , $20'$ N. Lat.; that at the foot of the *Mettenberg* is about equal to that of *Moscow*, 55° , $47'$ N. Lat.; or to that of *Drontheim*, 63° , $26'$ N. Lat.; and at *Grindelwald* it is about the same as at *Königsberg* in 54° , $42'$ N. Lat.* Such various mean temperatures and such various climates are, therefore, crowded together in the vicinity of that glacier.

The observations and experiments which have formed the subject of this chapter, answer the question, whether the increase of temperature towards the centre of the earth follows the same law, departing from all points situated on the same level, in the negative. The experiments have also made us acquainted with the chthonisothermals, lines of equal temperature, which, rigorously speaking, only remain parallel with the surface in plains within a very limited space, but bend upwards under mountains, and suffer a depression under lakes, seas and glaciers; thus always forming a greater or less angle with the horizon. Besides this, they must be a function of the curvatures found by Von Humboldt in the isothermal lines; for just as little as these coincide with the latitudinal lines of the earth,† will also the points of equal temperature in the interior of the earth be situated at equal depths in the same latitudinal circle.

I will conclude this chapter with an application of the fact, that the chthonisothermal lines curve upwards in mountains, to

* Kämtz Lehrbuch der Meteorologie, ii. 88.

† Schweigger's Journal, xxv. 261.

the theory of the creation of those warm springs, which rise at the foot of high mountains. As an example, I will take the warm springs of the baths of *Leuk*, in the canton *Wallis*.

The highest point near the *Leukerbad* is the *Balm Horn* (11,415 feet above the level of the sea). Now if, according to Chap. XVIII, the mean temperature of the soil is 32° at a height of 6195 feet, and if the decrease of temperature at the surface is $2^{\circ}.25$ in every 677 feet additional height, the mean temperature at the summit of the *Balm Horn* must be $+ 14^{\circ}.56$. If, further, the angle which the steep sides of the *Balm Horn* form with the horizon is 45° , and this mountain be considered as a cone; we find from the above formula that the increase of temperature from the summit towards the interior, is equal to $2^{\circ}.25$ for every 145 feet. The temperature 32° must, therefore, be found in the interior of the mountain, at a depth of 1123 feet from its summit, or 10,292 feet above the surface of the sea, and water may be supposed to exist there in a liquid state. From there to the level of the *Baths of Leuk* (4275 feet above the sea,* the increase of temperature, supposing it to continue to advance $2^{\circ}.25$ in 145 feet, must amount to $125^{\circ}.37$. If, then, we imagine water to collect in the *Balm Horn* at an elevation of 10292 feet, and to flow down through clefts in the interior to the level of the *Baths of Leuk*, these waters will have become heated on their way to a temperature of $125^{\circ}.37$, and will appear at the surface with this temperature, which is equal to that of the hottest of the springs of *Leuk*. There is no contradiction in supposing liquid water to exist in the interior of a mountain under a covering of perpetual snow. We find spring-water in mines, even when the surface has been covered for months with snow. At *Bogosłowsk*, where the earth is covered with snow during the greater part of the year, the quantity of water in the mines is nevertheless no greater in summer and autumn than in winter, and only increases in spring, when the flood of the meteoric waters is considerably increased by the sudden melting of the snow, and the overflowing of the rivers.† At *Hudson's Bay*, where the mean temperature is far below the freezing point,

* According to Michaelis, (p. 272.) 4402 feet.

† Kupffer in Poggendorff's *Annal.* vol. xv. p. 185.

springs flow through the winter, under a covering of ice and snow.* The supposed collection of water in the interior of the *Balm Horn* (which supposition is justified by the sinking of such enormous bodies of water as those of the *Dauben See* on the *Gemmi*, as well as by other phenomena, from which it is evident that the limestone has there suffered very considerable fissures in the interior) may be fed during the summer by the partial melting of the snow, for even on the summit of *Mont Blanc* it sometimes rains during the warm summer months, and the snow is there sometimes seen to begin to melt.

These considerations prove the possibility of the creation of warm springs in the Alps, when water in the interior of the mountains comes down from a great height, and, after passing through the warmer strata of the earth, makes its appearance in the valleys below. Such warm springs may even rise in very considerable elevations, provided there be still higher mountains in the environs. I will only bring forward one example more: if water should penetrate from the above mentioned mines of *Guanaxuato* in *Mexico*, where the temperature is already as high as $98^{\circ}.15$ into the interior of the mountains, as low as the level of the sea, its temperature would then have risen to $189^{\circ}.50$. Thus, then, in the high mountains of *America*, boiling hot springs may be produced, merely by the infiltration of meteoric waters into the interior of the earth, at an elevation of 9000 to 10,000 feet, and their reappearance at the level of the sea. And as this height is more than 4000 feet below the limits of perennial snow, the infiltration of the meteoric waters may be supposed to continue uninterruptedly in winter as well as in summer. The existence of such thermal springs, therefore, does not require that the waters should be brought to the surface by hydrostatic pressure.

* Captain James, 1631. See Von Buch in Poggend. Annal. xii. 450.

CHAP. XVIII.—*In what proportion to the height above the lowest points of the Earth's surface is the decrease of the Temperature of the Air and of the Soil? and is this Decrease the same at all parts of the Earth?*

There are various causes which influence the decrease of temperature with the height. Such are,

1st, The configuration of the earth's surface.

2dly, Local circumstances and climate.

3dly, The seasons.

4thly, The time of day.

Let us examine these causes more closely.

De Saussure* already remarked the more rapid decrease of the temperature on steep mountains, and Von Humboldt was led to the same conclusion, by comparing the temperature of the air on elevated plateaux, with that of the summits of mountains. He found, namely, that such plateaux, or narrow valleys, were warmer than the steep declivities of mountains, or than such strata of air which, instead of being in immediate contact with projecting parts of the earth's surface, rested upon other strata of air. On the other hand, the decrease of temperature from the level of the sea will be slower on extensive and gently rising chains of mountains, than on mountains having a steep ascent. As the lofty *American* chains of the *Peruvian* and *Mexican Andes*, to the height of *St Gothard*, form one immense mass, and up to that height comprise a surface of 120 square geographical miles, the decrease of temperature in the inhabited regions of the *Andes* is slow, but becomes suddenly more rapid where the less massive rocks rise 10,800 to 12,000 feet in isolated cones upon their broad basis. Thus Von Humboldt found a decrease of temperature of $2^{\circ}.25$ in 996 feet, between the level of the sea and the *Indian* village of *Calpi*; but the same decrease took place in every 618 feet, from *Calpi* to the highest point on the chain of the *Chimborazo*, or in the last 8292 feet. But taking the whole column of air of 18,072 feet together, the decrease of $2^{\circ}.25$ took place in every 714 feet. Between the surface of the sea and *Quito*, *Popayan* *S. Fe de Bo-*

* *Voyages dans les Alpes*, iv. § 935.

gota, and *Mexico*, which lie on that extensive plateau, we find from their respective mean temperatures a difference of elevation of 964 to 1090 feet* for every degree of temperature. Ideler† shews, that the influence of plateaux and broad ridges on the decrease of temperature in the *Himalaya* mountains is still more considerable.

Besides these general effects of the configuration of the earth's surface which are independent of latitude, there are others which are closely connected with the geographical situation of the place. Thus, under the equator and in low latitudes, the generation of heat must be greater on plains than on steep mountains, because the rays of the sun fall almost or quite perpendicularly upon the former, while with the latter they make an acute angle. In higher latitudes the contrary takes place on the sides of mountains which lie opposite to the sun. In the northern temperate zone, there may, therefore, be a slower decrease of temperature on the southern declivity of a mountain than on the northern or on gently sloping hills.

Climate and local circumstances, which have the effect of lowering the limits of perpetual snow, must, of course, also have some influence on the decrease of temperature. For the nearer the limits of perennial snow are brought at any place to the surface, the more rapid must be the decrease of temperature in proportion to the height. In the middle of an extensive chain of mountains, the decrease of temperature must consequently be more rapid than on both sides where the warmed air of the plains still operates.‡

In the same manner as glaciers and large accumulations of snow are enabled to lower the limits of perennial snow, so will they also have an influence on the decrease of temperature. From low valleys up to the glaciers, the decrease of tempera-

* Von Humboldt, in Gilbert's Annal. xxiv., 26-36; and xxxi, 369.

† Ideler ueber die Abnahme des Wärmestoffs mit der Höhe, p. 103.

‡ According to De Saussure (Voyages dans les Alpes, § 942), the limits of perennial snow are lowered more than 600 feet, by accumulations of snow, or by water resulting from the melting of snow. In like manner, Ramond asserts that the limits of perpetual snow, under the latitude of the Pyrenees, form a curve which descends from both ends of the chain to the middle, and which is therefore its lowest point. V. Buch, in Gilb. Ann., xli. p. 18.

feet in July, and in 946 feet in December ; making a difference of 400 feet between the coldest and the warmest month.*

Equally large differences are found between different hours of the day. Thus, the following results were obtained from corresponding observations at the following places :—

	Difference of height corresponding to 2°.25 difference of Temperature.	Hour of Observation.
Col du Géant, July,†	538 feet.	2 P. M.
	808 —	4 A. M.
Zürich and Rigi Culm, June,‡	453 —	5 P. M.
	700 —	5 A. M.
Geneva, Zürich, and Faulhorn, from 11th September to 5th October,‡	594 —	4 P. M.
	1174 —	5 A. M.
In heights of 1000 to 2400 feet between Poppelsdorf, the Siebengebirge, and the Hohenacht, I found, on the 28th March and the 1st June 1833, by corresponding observations, made every quarter of an hour of the day and night,	1148 — 667 — 1246 — 917 —	} in the Day. } in the Night.
At the time of the daily maximum of temperature,	264 —	
At the time of the minimum,	1560 —	

At what height do the yearly and daily variations of tempe-

* In the spring, on the other hand, when the snow is already melted in the low valleys of the Alps, but still covers the summits of the mountains, the difference of temperature between the plains and the mountains is so great, that a difference of 2°.25 may sometimes be reckoned upon, in a difference of height of 60 to 160 feet. During the five days which Von Humboldt and Gay-Lussac spent, in the month of May, at the convent of *Mont Cenis*, they found the thermometer constantly 27°.00 to 33°.75 lower than at *Lanslebourg*, although the difference of height between these two places is hardly 1944 feet. Gilbert's *Annal.*, xxiv. p. 22. Hugi found the temperature on the *Weissenstein* higher than at *Solothurn*, in the winter of 1829-30. Kastner's *Archiv für Chem. u. Meteorol.*, iv. p. 130. On the 6th January 1833, I found a mean temperature, from observations made every half hour from sunrise to sunset, at *Poppelsdorf*, + 23°.49, and on the *Petersberg*, 838 feet higher, only + 23°.68. On the other hand, on the 29th December 1832, I found, from similar corresponding observations at *Poppelsdorf* and *Burgbrohl*, which only lies about 250 feet higher than the former place, but six or seven leagues to the south-east of it, a mean of + 45°.36 for the former, and + 33°.37 for the latter place. It was just on this day that a frost set in with a south-east wind, and thus, the cold air descending into the deep valley of *Burgbrohl*, suddenly produced this great decrease of temperature between the two places.

† De Saussure, *Voyages dans les Alpes*, § 2050.

‡ Kämtz in *Poggendorff's Ann.* xxvii., 345.

rature cease? During the above observations, the extent of the variations of temperature were,

In Zürich,	12°.73
And at the same time on Rigi Culm,	6°.90
Again at Zürich,	21°.58
And at the same time at Geneva,	14°.92
And on the Faulhorn,	8°.50

From this it indeed appears that the extent of the variations of temperature is already considerably diminished in a difference of height of 4203 feet, between *Zürich* and *Rigi Culm*, and in 6866 feet, between *Zürich* and the *Faulhorn*; but we should be drawing our conclusions too hastily were we to infer that the point where the variations of temperature entirely disappear cannot lie very high. The extent of these differences of temperature does not only depend on the height, but also on other causes, as is proved by the great difference between *Zürich* and *Geneva*, which places are both at the same height above the level of the sea. Even on the summits of the highest mountains in *Switzerland* variations of temperature are still found. Thus, it sometimes rains on the top of *Mont Blanc* during the hot summer months, and the snow sometimes begins to melt there. Zumstein* observed a temperature of + 51°.12, on the 12th August 1819, on *Mont Rosa*, 13,920 feet above the sea. Parrot† experienced an oppressive heat on the *Lesa glacier*, on the southern side of the *Rosa*, at an elevation of 10,576 feet above the sea. Between the tropics, the point where the variations of temperature cease, is probably not situated so high as in the temperate zones; because, on the level of the sea, the yearly and daily differences of temperature are there confined within very narrow limits. However, Boussingault‡ relates that, on the 26th December 1831, a thermometer, suspended free in the shade of a rock on *Chimborazo*, at a height of 18,480 feet above the sea, and 3654 feet above the limits of perennial snow, the greatest height to which mountains have yet been ascended by men, and where the mean temperature of the air is probably + 23°.0, shewed + 46°.04; and

* Gilbert's Annal, vol. 63. p. 391.

† Schweigger's Journ. xix., 386.

‡ Poggendorff's Ann. xxxiv., p. 206, and Edinburgh New Philosophical Journal, vol. 19. p. 98.

that the snow was in such a state as to be about to melt. So far, then, it is certain that, at the highest points of our globe, there are still variations in the temperature of the air. Whether this disappears at the height of 34,158 feet, as Von Lindenau* supposes, must remain a question.

But the variations in the temperature of the soil disappear in accessible heights, even at a small depth beneath the surface. According to Boussingault's observations (Chap. VIII), in the *Cordilleras*, the temperature of the soil is there constant even at a depth of one foot, on the level of the sea. As in higher latitudes the depth to which the influence of the external temperature penetrates, is much greater than between the tropics (Chap. VIII.), the same must also be the case at all heights accessible to man.

According to the observations which I have been making for a year past, in front of the chemical laboratory and on the top of the *Löwenburg*, situated 1173 feet higher, the yearly variations of the temperature of the earth at the depth of four feet, amount, at the former place, to $19^{\circ}.12$, and at the latter to $15^{\circ}.63$. For reasons which will be given below, I think, that the yearly variations of temperature on the *Faulhorn*, 8178 feet above the sea, and 6784 feet above the *Löwenburg*, are not less considerable at a depth of four feet. It is, however, to be expected, that at the higher points of the Alps, where the earth is covered with perpetual snow, the temperature of the soil at this depth below the surface is constant.

Can the decrease of temperature with the height be considered as an arithmetical progression in the strictest sense of the word?

Von Humboldt's observations, according to which, the difference of height corresponding to $2^{\circ}.25$ difference of temperature is greater, the greater the difference of height between the two points of observation, seem indeed to indicate, that between the tropics the decrease of temperature becomes less and less rapid from the level of the sea nearly to the regions of perpetual snow. And Humboldt† himself doubts whether this de-

* *Monatliche Correspondenz*, xxi, 119. See Ideler, p. 103.

† *Gilbert's Annal.* xxiv. p. 48.

crease does follow an arithmetical progression. Schmidt* has arrived at the same conclusion from considerations of a different nature. Observations at eighteen points in *South America*, made exactly where Boussingault made the observations communicated below, seem also to indicate a diminishing decrease of temperature.† But it is probable that this apparently diminishing decrease of temperature is due to another cause. For, since observations by day give a more rapid, and by night a slower decrease of temperature in the air, and consequently the mean between the two is the expression of the real decrease, we shall obtain a more accurate result the greater the difference of height between the points of observation is, where *single* observations only are made, from which the decrease of temperature is to be calculated; for, the daily variations of temperature at the lower point will have the less influence on the difference of height in which the temperature decreases $2^{\circ}.25$, the greater the difference of height between the two points is. So that, if observations be made at different heights at the time of the daily maximum temperature, an apparently retarded decrease of temperature will be found; and, if at the time of the minimum, it will be apparently accelerated. But by far the greater number of observations at different heights have certainly been made nearer to the daily maximum than to the daily minimum of temperature. We are, therefore, not justified by these observations, in concluding on a diminishing decrease of temperature from the surface of the sea to the greatest heights accessible to man, namely to the limits of perennial snow. Gay-Lussac's observations during his aeronautical excursion are equally insufficient to justify a contrary conclusion.§

* Gilbert's Annal. vol. lxii. p. 309.

† Ibid. vol. lxii. p. 309.

‡ Mémoires d'Arcueil, iii. p. 580. Semanario del Nuevo regno de Granada. vol. i. p. 273. ii. p. 93-341. See Ideler, p. 95.

§ Gilbert's Annal., xxiv., p. 28. and xxxi. p. 32. Gay-Lussac himself remarks, that his thermometers did not keep pace with the temperature. And how could the thermometers be expected to keep pace with the temperature of the air, considering the velocity with which an aeronaut makes his ascent? See also the remarks of Humboldt in the same, p. 34. and of Gilbert, p. 32.

The means of determining the decrease of temperature with the height, are :

1st, Observations on the temperature of the air.

2d, Observations on the temperature of springs ; and,

3d, Direct observations on the temperature of the soil.

The next question to be asked is, Whether the decrease of temperature in the air, and that of the soil, in proportion to the height, follow the same progression ?

If, in general, according to Chap. VI, there is no reason for supposing a difference to exist between the mean temperature of the air and that of the soil, this question is already answered. In this case the determination of the mean temperature of the air or of the soil at various heights, would be sufficient to solve the problem. That between the tropics there is no difference between the mean temperature of the air and that of the soil, we have seen in Chap. VI. In the temperate zone so few observations have been made, that the means of comparison are wanting.

From all that has been said it follows, that between the tropics, the decrease of temperature in the air may be found with a tolerable degree of exactness, by single corresponding observations, made at different heights. The most accurate results, however, are only to be got from the yearly mean. Von Humboldt* takes the mean of all his observations between the tropics at 654 feet difference of height for $2^{\circ}.25$ difference of temperature, for the stratum of air comprised between the surface of the sea and 3000 feet above it. As this philosopher made most of his observations in the day-time, it may be assumed, as we have said above, that they have yielded a somewhat too rapid decrease of temperature.

Let us compare this result with Boussingault's observations on the decrease of the temperature of the soil in the *Cordilleras*, between 11° north and 5° south latitude. This philosopher ascertained the temperature of the soil at no less than 128 places, at all heights between the surface of the sea and the limits of perennial snow, after the manner already described (Chap. VI).

* Reisen, ii. p. 492. Formerly Von Humboldt supposed it to be 726.6 ft. Gilbert's Annal. xxiv. 48.

In order from these to calculate the decrease of temperature with the height, it was necessary to assume a fixed temperature at a certain height; a supposition which, indeed, strictly speaking, does not actually exist. We might have taken for our fixed point, either the temperature at the level of the sea, or on the limits of perennial snow. To take the former as a *terminus a quo* did not seem convenient, as the mean temperature of the places on the level of the sea varies between $78^{\circ}.8$ and $83^{\circ}.30$, which difference would give a difference in the decrease of temperature, from the surface of the sea to the limits of perennial snow, of 71 feet in $2^{\circ}.25$. I, therefore, took $34^{\circ}.92$, given by Boussingault as the mean temperature on the limits of perpetual snow (14474 feet above the sea), as a constant value, and from it and the mean temperatures of the places below it, I calculated the difference of height corresponding to $2^{\circ}.25$ difference of temperature. This gave the 3d column of numbers contained in the following table. The heights given by Boussingault in metres are reduced to Paris feet, and the centesimal degrees to those of Fahrenheit.

NAMES OF PLACES.	Height above the Sea.	Mean Temperature.	Difference of Height corresponding to $2^{\circ}.25$ Difference of Temp.	NAMES OF PLACES.	Height above the Sea.	Mean Temperature.	Difference of Height corresponding to $2^{\circ}.25$ Difference of Temp.
Cumana, .	0	$81^{\circ}.50$	713	Cayma, .	1,210	$81^{\circ}.72$	650
La Guayra, .	0	$80^{\circ}.60$	727	Estanque, .	1,311	$80^{\circ}.15$	668
Rio Hacha, .	0	$82^{\circ}.62$	696	San Martin, .	1,330	$79^{\circ}.92$	672
Santa Marta,	0	$83^{\circ}.50$	686	Maracay, .	1,351	$77^{\circ}.9$	702
Baranquilla, .	0	$82^{\circ}.17$	702	Haguila, Choco,	1,431	$79^{\circ}.02$	680
Carthagena, .	0	$81^{\circ}.50$	713	Valencia, .	1,502	$78^{\circ}.8$	680
Panama, .	0	$81^{\circ}.05$	721	Neiva, .	1,597	$77^{\circ}.0$	704
Tumaco, .	0	$79^{\circ}.02$	754	Barquisimeto,	1,607	$78^{\circ}.12$	686
Guayaquil, .	0	$78^{\circ}.8$	757	Mariquita, .	1,687	$77^{\circ}.67$	687
Payta, .	0	$80^{\circ}.82$	724	La Vittoria, .	1,727	$78^{\circ}.12$	680
Esmeraldas, .	0	$79^{\circ}.47$	745	Alto de Mombú.	1,794	$77^{\circ}.0$	693
Barranca Nuevo,	0	$81^{\circ}.72$	710	Antioquia, .	1,936	$77^{\circ}.22$	677
San Carlos, .	520	$81^{\circ}.50$	687	Tocuyo, .	1,936	$75^{\circ}.87$	704
Novita, Choco,	554	$79^{\circ}.02$	725	Truxillo, .	2,262	$77^{\circ}.0$	668
Honda, .	640	$81^{\circ}.72$	677	Tampo de la Or- } queta, . }	2,262	$77^{\circ}.0$	668
Giramaena, .	665	$81^{\circ}.05$	689	San Geronimo,	2,318	$74^{\circ}.97$	695
Tomependa, .	1,200	$78^{\circ}.35$	701				

NAMES OF PLACES.	Height above the Sea.	Mean Temperature.	Difference of Height corresponding to 2° 25' Difference of Temp.	NAMES OF PLACES.	Height above the Sea.	Mean Temperature.	Difference of Height corresponding to 2° 25' Difference of Temp.
Truxillo, .	2,561	74.97	682	Pamplona, .	7,113	61.70	643
Villetta, .	2,582	77.9	638	La Baxa, .	7,243	59.0	703
Chami, à la rivière,	2,773	72.50	718	Alausi, .	7,480	59.0	680
Caraccas, .	2,881	71.37	732	Ubata, Socorro,	7,495	61.7	611
Roldanillo, .	2,949	75.87	648	La Chorrera, .	7,673	61.02	612
Cartago, .	3,013	76.10	642	Sonson, Antioquia,	7,803	57.20	703
Ruga, .	3,032	75.87	644	Pelileo, .	7,821	59.67	629
Toro, .	3,044	75.87	643	Ubate, .	7,886	59.90	619
El Bordo, .	3,112	74.75	657	Santa Rosa de Osos,	7,938	57.65	676
La Moyarra, .	3,133	76.32	633	Chiquinquirá,	7,994	60.80	589
Guaduas, .	3,146	74.75	655	Pasto, .	8,034	58.55	643
La Plata, .	3,226	74.75	653	Cuenca, .	8,101	60.12	596
Anserma Nuevo,	3,232	74.75	653	Paisbamba, .	8,107	55.40	731
Santa-Ana, .	3,257	71.60	706	Santa Fé de Bugota,	8,129	58.10	644
Llano grande, .	3,340	73.62	665	Puracé, .	8,160	55.62	719
El Palo, .	3,420	73.85	656	Ambato, .	8,246	61.02	563
Carache, .	3,623	70.25	708	Muechisa, .	8,314	56.30	679
Juanambú, .	3,629	71.15	693	Guaranda, .	8,378	59.0	597
Vega de Zupia, .	3,771	70.70	691	Santa Rosa, .	8,446	57.87	618
Sombrerillo, .	3,912	69.12	715	San Pablo, .	8,532	57.20	689
Ibagué, .	4,072	71.15	662	Tunja, .	8,649	56.75	633
Hacienda del Rodeo,	4,128	68.0	723	Caxamarca, Peru,	8,803	60.8	518
Arma, .	4,365	68.9	688	Latacunga, .	8,806	59.9	537
Marmato, .	4,389	68.67	690	Riobamba, .	8,834	61.47	502
Mandiva, .	4,392	74.52	590	Quito, .	8,932	59.45	532
La Canada, .	4,669	70.25	644	Tusa, .	9,059	51.8	670
La Orqueta, .	4,679	66.65	717	Chita, .	9,142	53.60	677
Medellin, .	4,762	68.90	662	El Guavo, Riobamba,	9,145	51.8	749
Merida, .	4,983	71.60	600	Mucuchies, village,	9,206	57.87	544
Cabullo, Venta,	5,039	66.87	683	Pucará, near Ibarra,	9,219	58.55	530
Rodeo, Zupia, .	5,260	66.65	676	Tulcan, village,	9,295	55.17	608
Estrella, Antioquia,	5,297	65.75	689	Malvasas, Popayan,	9,357	54.27	627
Quinchia, .	5,467	65.75	676	Tuqueres, village,	9,563	50.	775
Anserma Viejo, .	5,503	63.50	729	Pinantura, farm,	9,711	52.02	666
Venta de Berruecos,	5,507	63.95	715	Callo farm, .	9,726	54.02	595
Popayan, .	5,568	63.50	724	Paramo de Hervé,	9,748	50.45	726
Riosucio, Zupia, .	5,596	66.65	648	Vetas, village,	9,905	49.10	770
Ferme de Orthega,	5,651	66.42	651	Cumbal, village,	9,908	51.35	668
Bannos, .	5,876	62.15	736	Alto de Salaza,	10,545	47.30	766
Azufral du Quindí,	6,085	61.02	749	Los Paramos, .	10,773	47.30	725
El Cedrito, Hervé,	6,159	67.10	601	Lisco farm, .	10,923	47.97	664
Suatí, .	6,214	68.0	582	Pantano Vargas,	11,302	46.85	653
El Moral, Quindí,	6,258	64.40	649	Metairie d'Antisana,	12,533	39.87	1,000
Loxa, Peru, .	6,433	64.40	636	Azufral de Juan,	12,678	38.97	1,151
Samenga, .	6,467	63.50	653	Snow limit, .	14,774	34.92	1,687
Aguadas, Antioquia,	6,765	61.70	672	Glacier of Antisana,	16,805	28.85	1,758
Zotara, Popayan,	6,944	60.8	679				679
Almaguer, .	6,956	62.60	635				
Ibarra, .	7,006	63.05	622				
				Mean, ...			679

If we look at the greatest differences in the third column of figures between places situated at about the same height above the sea, we find that they exceed only three times the above-mentioned difference of 71 feet. This justifies the conjecture that these differences are only due to the local influence of climate. At least on the sea coast no other cause can be imagined. The numbers of the third column shew neither an increase nor decrease up to the *Métairie d'Antisana*. It is true the highest number, 775 feet is found near the end, but the next, which is 757 feet, is found quite at the beginning of the series. The case is nearly the same with respect to the minimum, 518 feet. The two last numbers but one, 1000 and 1151 feet, are, however, astonishingly high, and from this it would appear that the decrease of temperature becomes slower near the limits of perpetual snow. But the last number, 769, is again about equal to the mean. The two last numbers but one, 687 and 758, were found from the differences between the highest and lowest mean temperatures on the level of the sea, and that of the limits of perennial snow. They shew the above-mentioned difference of 71 feet, which may be considered to a certain extent as the maximum effect of climate.

The means of the four columns of results in the table being so nearly equal, proves that between the tropics, from the surface of the sea to the limits of perpetual snow, a *constant* decrease of temperature takes place. However, *Métairie d'Antisana* and *Azufral de Juan* must be excepted.

The mean of all these results gives a difference of height of 677 feet for $2^{\circ}.25$ difference of temperature, between the surface of the sea and the limits of perennial snow.

This value only surpasses the mean, which Von Humboldt found from his observations on the decrease of temperature in the air, by 23 feet. It might, indeed, be conjectured that this excess was due to Humboldt's observations having been made in the day, and, therefore, gave a somewhat accelerated decrease of temperature; but, in general, no great weight can be attached to this difference, as the numerical elements which influence observations of this sort are very various.* Their cor-

* The differences of height found from Boussingault's observations, for $2^{\circ}.25$ difference of temperature, for example, would have been smaller, if the temperature at the limits of perennial snow should be lower than $+34^{\circ}.92$.

responding so nearly seems rather to lead to the conclusion, that between the tropics the decrease of temperature in the air and in the soil follow the same law of progression.

For the reasons above given, the decrease of temperature in the air in the temperate zones can only be deduced from the known mean temperatures at different heights. Here, then, we are confined to the habitable regions. All that we as yet know of the decrease of the temperature of the air in the temperate zones is from the corresponding observations made during several years at *Geneva* and on the *St Bernhard*. The mean of these observations gives a difference of 777.5 feet for every degree of Reaumur, or 2°25 degrees of Fahrenheit. This result exceeds the mean of Humboldt's observations by 123 feet, and that taken from Boussingault's by 100 feet; but it is far lower than the former of these philosophers found for mountains having a very gradual ascent. But as *St Bernhard* is 24 leagues distant in a straight line from *Geneva*, and the difference of height between the two places is only 6477 feet, it may be considered as being a case of gradual ascent; and the temperature must decrease less rapidly than if the mountain had a steep precipitous ascent. To conclude that the decrease of temperature in the temperate zones is less rapid than between the tropics, would, therefore, certainly be premature.

The first question to be decided is, whether, in the temperate zones, as between the tropics, the mean temperature of the soil and of the air are identical, in elevated situations, as well as on the level of the sea. If this be found to be the case, we may, instead of the tedious observations in the air, which at uninhabitable heights are, indeed, quite impracticable, substitute observations in the soil, which, although also combined with difficulties, are yet possible to be accomplished. But this question can be most easily answered by the observations at the *Monastery of St Bernhard*, where the mean temperature of the air is known, and where meteorological observations continue to be made.

The simplest method of obtaining the temperature of the soil, as I have found, is, to dig a hole about four feet deep, and to sink a wooden case of the same depth into it, and then to fill up the surrounding space with earth or sand. The case should

be just so large as to admit a common wine bottle. The bottle, filled with water, stands on a piece of board, which is half an inch smaller than the opening of the box. Over the bottle is placed another piece of wood, which is held fast to the former by iron wires, and to the upper board is attached a wire, which is long enough for the observer to be able to reach it with his hand. The space above the bottle is filled with a bad conductor, for instance with tow, and the box is covered over with a board, upon which some stones are placed to prevent the entrance of the rain water, and the whole is covered with moss to preserve it from unauthorized observers. After the lapse of four weeks the first observation may be made; for in that time the disturbances, caused in the thermometrical relations by making the hole, will have entirely subsided. However, it cannot be otherwise than advantageous to allow a longer time for the restoration of the equilibrium before the first observation. As at the depth of four feet the temperature continues to rise uninterruptedly from the minimum to the maximum, and to fall from the latter to the former, monthly observations are quite sufficient to give the yearly mean temperature. Indeed, there can be no doubt that 12 observations made in this manner will give a more exact mean than observations made three times a-day in the air, without being made also during the night.

I have found that, even where there is a difference of temperature of $22^{\circ}.50$ between the atmosphere and the water in the bottle, the temperature of the air has no influence on that of the water, during the first two minutes. But two minutes are quite sufficient for a sensitive thermometer to assume the temperature of the water.*

In this manner I have observed the temperature of the soil, since the 28th February 1835, in front of the chemical laboratory near *Bonn* and on the *Löwenburg*, which rises with a steep ascent from the *Rhine* to a height of 1173 feet above the other point of observation. The results of the first year of my observations are as follows:—

* In the spring of 1835, I requested the monks of the *Monastery of St Bernhard* to add similar observations on the temperature of the soil to their valuable meteorological observations; but I have not yet heard whether my request has been attended to.

		Bonn.	Löwenburg.	Difference.
1835.	February 28.	42°.12	39°.76	2°.36
	April 9.	44.60	41.0	3.60
	May 10.	48.87	42.8	6.07
	June 14.	55.40	47.97	7.43
	July 12.	56.52	50.0	6.52
	August 8.	59.22	52.92	6.30
	August 30.*	59.0	54.05	4.95
	October 21	53.60	50.22	3.38
	November 9.	49.55	47.30	2.25
	December 21.	43.25	42.35	0.90
1836.	January 13.	40.10	40.10	0.0
	February 14.	41.0	38.41	2.59
	Mean,	49.44	45.57	3.87

We see that the maxima and minima do not happen at the same time; but that they take place later on the more elevated spot, and that as the decrease of temperature varies according to the seasons, so does also the decrease of temperature in the soil vary. The mean difference of temperature between *Bonn* and the *Löwenburg* gives a mean decrease of temperature of 2°.25 in every 683 feet between the two places. This number is so nearly the same as the mean of Boussingault's observations, that we may certainly be allowed to consider the decrease of temperature with the height, between the tropics and in 51° N. Lat., as identical, at least to the height of 1173 feet.

In these observations another circumstance must be taken into consideration, namely, whether each two points of observation, at different heights, must lie in the same position with respect to the sun; that is to say, whether they must both lie in the shade, or be exposed to the sun; or has this no influence on the yearly mean? The point of observation in front of my laboratory lies during the whole year in the shade; that on the *Löwenburg* is in a little hollow on the top of the mountain,

* I was prevented from observing from the 8th August till the 21st October by my journey to the Alps, and afterwards by indisposition. The observations on the 30th August were made by an observer whose accuracy may be depended on. However, this gap can have no perceptible influence. Neither can it have been prejudicial to the accuracy of the results, that the observations were not always made on the same day of the month, which was rendered impossible by my other duties and by unfavourable weather. The object of these observations was not so much to ascertain with the utmost exactitude the mean temperature of the places, as to learn the mean difference of temperature between two places situated at different heights.

and, although it is sheltered from the direct action of the sun's rays by the surrounding bushes, is yet very much more exposed to its influence than the former spot. The place where I am making the observation, mentioned in Chap. VIII., for ascertaining the depth to which the influence of the external temperature is felt, is exposed to the sun during almost the whole year; if, then, the position of a place with respect to the sun, has any influence on the yearly mean, it would shew itself most distinctly between this spot and that in front of the laboratory.

The observations which I made at the same time at these two spots, extended from October 1835 to February 1836. From this time till April they were unavoidably interrupted, in order to sink the shaft deeper, but after April they were continued. The slight difference of two feet below the surface cannot have any considerable influence on the results.

	Four feet deep in the shade.	Six feet deep in the sun.	Difference.
1835. October 20.	53°.82	54°.72	—0°.9
November 4.	51.35	51.01	+0.34
... 20.	45.95	44.60	+1.35
December 2.	46.85	44.82	+2.03
... 21.	43.25	42.05	+1.20
1836. January 13.	40.10	38.75	+1.35
February 14.	41.00	38.86	+2.14
April 12.	44.15	43.81	+0.34
May 16.	48.20	48.20	0
... 23.	49.77	50.67	—0.9
... 30.	49.89	51.57	—1.68
June 6.	50.90	52.14	—1.24
... 13.	52.14	53.38	—1.24
... 20.	54.05	55.40	—1.35
... 27.	54.95	56.75	—1.8
July 4.	56.07	58.21	—2.14
... 11.	56.97	60.12	—3.15
... 18.	57.65	61.02	—3.37

The difference, therefore, at the end of October and in the middle of May is 0; but from the end of October till the middle of May, the temperature of the place in the shade is constantly higher than that of the place exposed to the sun; and from May till October it is constantly lower. Whether the yearly mean temperature of the two places is the same, or whether, as we should be inclined to conclude from the above observations, the mean of the place exposed to the sun is higher than the other, must be decided by a series of uninterrupted

observations. At any rate, the difference does not seem to be great, and it will, therefore, be of little consequence, if, in making observations on the temperature of the soil at various heights, the position of the places of observation with regard to the sun be entirely disregarded. However, should the localities permit, it would always be advantageous at each station to choose two spots for observation, the one in the shade, the other exposed to the rays of the sun.

I am continuing my observations on the *Löwenburg*, but confine myself to the seasons in which the maximum, minimum, and medium take place.

	Bonn.		Löwenburg.	Difference between a and c.	Difference between b and c.
	4 feet deep in the shade. a	6 feet deep in the sun. b			
1836. June 13.	52°.13	53°.37	45°.95	6°.18	7°.42
July 11.	56°.97	60°.12	50°.45	6°.52	9°.67
August 28.	58°.03	60°.68	51°.46	6°.60	9°.22
October 16.	54°.83	55°.62	50°.00	4°.83	4°.61

Comparing these observations with those made at the same season in 1835, we find, *1stly*, that in June 1836, the temperature was considerably behind that of 1835, which was a consequence of the cold winter and spring; *2dly*, that in July 1836, the temperature already exceeded that of July 1835, which must be attributed to the month of June having been exceedingly warm; *3dly*, that in 1835, the greatest difference of temperature between the upper and lower station took place in June, whilst in 1836, it did not happen till July; and that, in the latter case, it was 0°.9 lower than in the former; and, *4thly*, that the differences of temperature between *b* and *c* were much greater than between *a* and *c*.

In order, in like manner, to discover the decrease of temperature in the soil to still greater heights in our latitudes, I arranged, on the 30th August 1835, a similar apparatus on the *Faulhorn*, which rises to a height of 8178 feet, and the spot I selected was on the south side of the inn; and on the following day I found the temperature of the

water in the bottle to be $36^{\circ}.51$. However, no weight can be attached to this observation, as within twenty-four hours the disturbances caused in the temperature by digging the hole, could not yet have subsided. On the 22d September the brother of Mr Ziegler of *Grindelwald* observed a temperature of $37^{\circ}.62$. More reliance may be placed on this observation, which was made twenty-three days after the burying of the bottle. As we find by interpolation, that the temperature of the soil on the 22d September was, on the *Löwenburg*, $6^{\circ}.79$, and at *Bonn* $7^{\circ}.19$, higher than the mean, the mean temperature on the *Faulhorn* must be between $+30^{\circ}.84$ and $+30^{\circ}.45$, supposing its temperature to follow the same progression as at those two places.* But these values depend on suppositions which are still to be proved. I, therefore, request all natural philosophers and other travellers accustomed to such observations, who may happen to visit the *Faulhorn*, so celebrated for the grandeur of its scenery, to devote a few minutes to a similar observation, and to have the goodness to communicate to me the result. For this purpose I have committed a thermometer to the care of the innkeeper on the *Faulhorn*, Hans Bohren, of which the observer may make use. The landlord will have the kindness to direct the observers to the spot where the box is buried, and will draw out the bottle. Those who ascend the *Faulhorn* and *Grindelwald*, as is usually done, may make further inquiries of the pastor, Mr Ziegler, who, as I have before said, is making similar observations in his neighbourhood. Of course it is not to be hoped that observations will be made in every month of the year, as the innkeeper himself quits the *Faulhorn* at the end of October, and does not return there till May, and as, in general, during the winter months, it is almost if not quite impossible to ascend this mountain. But even if we only obtain observations in the summer months, we may still hope to succeed in deducing from them the probable scale of the yearly variations of temperature, and from this to obtain the yearly mean tem-

* It is, however, probable that the maximum on the *Faulhorn* happens later than at those two places, which are situated so much lower, and, in this case, the mean temperature would there fall still further below 32° . The calculations which follow below, and that which we learn from Heer (*Fröbel und Heer loco citato*, p. 322) on the duration of the warm season in the various regions of the Alps, speak in favour of this conjecture.

hard, the heights correspond tolerably well for all these places. On the average, then, the mean temperature would become $32^{\circ}.0$ at the height of about 6165 feet above the sea, for places situated between $48^{\circ} 10'$ and $46^{\circ} 12'$ north latitude, and at the height of 8200 feet, the supposed limit of the snowy regions in the Alps, the mean temperature would be $+25^{\circ}.25$. This nearly agrees with the observations of Pictet, according to which the snow first shews itself where the mean temperature is $+23^{\circ}.68$. But here we find a difference of $9^{\circ}.67$ between the mean temperature on the limits of perennial snow on the equator, as taken by Boussingault from the observations of Humboldt, and that of the limits of the snowy regions in the Alps. This difference, however, is reduced to $7^{\circ}.42$ if we adopt $+32^{\circ}.67$ as the mean temperature on the limits of perpetual snow at the equator, which is the value deduced from other observations of Von Humboldt.

As between the tropics the temperature of the soil shews no variations at the depth of one foot, it will shew still slighter variations at the height where the mean temperature is 32° . Snow, which there covers the ground, will therefore be unable to melt on its under surface. But on its upper surface, which is exposed to the air, the snow may partially melt during the summer, because the variations in the temperature of the air are always more extensive than those of the soil, even in the smallest depths, and the temperature of the air at that height between the tropics may, therefore, always rise a few degrees above 32° during the summer. In the temperate zones, on the other hand, the temperature of the soil still suffers considerable variations at that height, in which the mean temperature becomes 32° , and, therefore, rises in summer to several degrees above 32° ; supposing the soil not to be covered with glaciers, or any masses of snow by which the communication of heat from above would be prevented. Here, then, snow which covers the ground at that height, must melt away during the summer even on its under surface, and still more on its upper surface, which is exposed to the air, so that it must entirely disappear. This accounts for the possibility of perpetual snow being met with between the tropics, where the mean temperature is equal to or even above 32° , whilst in higher latitudes it

does not occur till we reach the regions where the mean temperature is several degrees below 32° , or where the maximum temperature of the soil is 32° .

I have determined the temperature of the soil at the depth of 12 inches, at four elevated spots in the *Swiss Alps*; and in the following table I have added to the results which I obtained, the mean temperatures of the places, calculated upon the principle above established, viz. that the mean temperature is 32° at a mean height of 6165 feet.

Date.	Place of Observation.	Height above the sea in Paris feet.	Temperature observed.	Calculated Mean Temperature.	Difference.
1835, Aug. 27.	At the Mettenberg, on the level of the Eismeer, . . . }	5129	44.37	35.43	8.92
Sept. 3.	Spital Matte, . .	5887	41.0^*	32.92	8.09
... 3.	Gemmi, . . .	6987†	38.52	29.28	9.25
Aug. 30.	Faulhorn, . . .	8178 {	$35.24^{\ddagger}$ $36.56 \parallel$	25.32 25.32	9.92 1.12

At places in low situations, as *Stockholm*, *Abbotshall*, and *Brussels*, the maximum temperature of the soil at the depth of one foot takes place in July. But if, as my observations on

* In a cleft in the rock the temperature, as low down as I could reach with my arm, was $40^{\circ}.55$, and the same was at a depth of 12 inches in the ground in a place exposed to the full power of the sun, I found a temperature of $41^{\circ}.45$. If the temperature of the numerous fresh-water springs which rise in that neighbourhood (Chap. IV.) give the true mean temperature of the soil, this must be $+37^{\circ}.40$. But these springs which rise out of the much-fissured rocks of limestone are probably thermal (Chap. I.), even though they proceed from the *Daubensee* (Chap. XI.)

† According to Michaelis (Frübel und Heer, p. 272) 7049 feet; according to others 6953 to 7160 feet.

‡ This is the mean of eighteen observations on the summit of the mountain, which were made every half-hour from $9\frac{1}{2}$ A. M. till $6\frac{1}{2}$ P. M., and at $5\frac{1}{2}$ A. M. of the 31st August. The maximum was $35^{\circ}.60$, and the minimum $35^{\circ}.15$.

|| This is the mean of the observations which were made at the same time as the others, but 40 feet below the summit on the southern declivity of the mountain. The maximum was $37^{\circ}.40$, the minimum $36^{\circ}.27$. Both series of observations were made at a time when the *Faulhorn* had been already some days covered with snow one foot deep. The places where the observations were made were, however, freed from the snow.

the *Löwenberg* give reason to suppose, the maximum at these more elevated points happens somewhat later, then it is probable that the observations made at the end of August and the beginning of September were already somewhat under the maximum.

The maximum, therefore, probably exceeds the observed temperatures at those places by $2^{\circ}.25$, perhaps more, and thus we should have at least $43^{\circ}.25$ for the maximum temperature of the soil on the *Spital Matte*, which is situated nearly at the height in which, according to our hypothesis, the mean temperature is 32° . But where the maximum temperature of the soil reaches $43^{\circ}.25$, no perpetual snow can be found. Even on the top of the *Faulhorn* the maximum is probably above $37^{\circ}.62$, so that here also perennial snow cannot be met with. Yet the summit of this mountain rises as high as the limits of perennial snow in the Alps are supposed to exist. However, these limits are supposed to rise on single insulated peaks, to a height of 8400—8700 feet, and on extensive chains of mountains to fall to 7800 feet.*

Besides the observations in the Alps, we have also those made at *Dresden*, *Freyberg*, and at several other places in the *Saxon Erzgebirge*, in the years 1830–1833, which furnish us with some data on the decrease of temperature with the height. For $2^{\circ}.25$ difference of temperature they give

Between	A Difference of Height	
	According to the arithmetical mean.	According to the method of smallest squares.
<i>Dresden and Freyberg,</i>	891,5	885,7
<i>Dresden and four different places in the Erzgebirge,</i>	770,7	680,2
<i>Freyberg and three different places in the Erzgebirge,</i>	677,5	640,2

From the thermometrical observations of the soil near the surface, made at various heights in the *Erzgebirge*, Reich calculated that the decrease of temperature in the soil there

* Ebel, Part II. p 49.—On the top of the *Seidelhorn*, which is 8580 feet high, I found no snow on the 18th August 1822; but in a ravine on the eastern side of the mountain, a considerable mass of snow was accumulated

amounts to 20.25 in 744 feet on the average. This result cannot be compared with the above, as the temperatures of the air and of the soil were not made at the same places, but at places very different in their climate; further, because the mean temperature at *Altenberg* in the years 1830–1832 shewed differences as great as those between that place and *Markus Röhling*; and lastly, because the observations on the temperature of the soil at *Altenberg* and *Johanngeorgenstadt* even shewed an increase of temperature with the height.

However, these observations seem also to prove that the decrease of temperature is slower in extensive gradually ascending mountains, but more rapid in steep ones. As there may, therefore, be an infinite number of gradations in the decrease of temperature between mountains which rise almost perpendicularly from the surface of the earth, and a gradually ascending inclined plane, all other circumstances being the same; only such observations can serve for a comparison, as have been made on mountains having a very steep ascent.

With respect to the decrease of temperature with the height in the frigid zones, we are totally unprovided with observations in those regions, which might serve as data in our calculations. We must, therefore, leave it undecided, whether the relations are the same or different from those which exist in the other zones. If Fourier's hypothesis,* that the temperature of space, or at least of that part of space in which the earth performs its orbit, is about equal to the mean temperature at the poles is correct, no decrease of temperature can be supposed to take place in proportion to the distance from the surface of the earth at the poles.

We now come to the last means of determining the decrease of temperature with the height, namely, the temperature of springs, which seems indeed to be the simplest method of all.

In Chapter VI. it has been shewn, that, under the most favourable circumstances, the mean temperature of the soil can only be determined from such springs as have not a constant temperature, because springs of constant temperature always rise out of strata which are situated much lower. But the

* Mém. de l'Institut. 1824, p. 580.

mean temperature of variable springs can only be found by means of monthly observations continued for a whole year, or by observing exactly at the time of their mean temperature. When once the time of the maximum or minimum is known, it is easy to determine the time of the mean, for this always happens three months after these extremes.

But mountain springs scarcely ever give the true temperature of the place at which they rise, but generally of a more elevated region, that is to say, they bring cold with them from above.—(Chap. IV).

From this it follows, that single observations on springs are of no use for the determination of the mean temperature of the soil, for repeated observations are necessary for deciding whether the springs have a constant temperature or not, and if not, when its mean happens. But it is impossible to discover whether a spring give the true temperature of the place, without the assistance of observations on the temperature of the soil itself. Thus it follows, that even monthly observations of mountain springs, continued for a whole year, cannot be of use for the determination of the mean temperature of the soil.

The following table contains the results of one year's observations made by me on the temperatures of eighteen springs which rise between *Poppelsdorf* near *Bonn*, and the highest points in the *Seven Mountains* (*Siebengebirge*), at which springs are still to be met with. It proves what we have just said most clearly.

The numbers between parentheses were determined by interpolation, but all the rest by observations, made for the most part in the middle of the month, excepting when other duties or unfavourable weather prevented it. As the greater number of these springs shewed but small variations from month to month, it could be of little consequence whether the observations were made a few days earlier or later in the month. The first seven springs rise all nearly on the same level, on the slope of the hills belonging to the lignite formation, which run from *Poppelsdorf* to *Godesberg*. The ground rises imperceptibly from the former of the places to the latter.

No. 1 is an artificial well 58 feet deep, which, like all other wells in this neighbourhood, is supplied with water from the *Rhine*. Its high mean temperature compared with that of the six following ones, is evidently caused by the increase of temperature towards the interior of the earth. The mean temperatures of 2—7 agree, however, tolerably well together, and the mean of these six might therefore be taken as the mean temperature of the soil between *Poppelsdorf* and *Godesberg*. However I exclude No. 5, because it rises from very near the surface, as is plain from its more extensive variations of temperature compared with the others, and because it evidently receives its water from the neighbouring hills. In this manner, then, we obtain a mean of $50^{\circ}.22$. The springs 8—18 are all situated on the other side of the *Rhine*, in the *Siebengebirge*, and rise by degrees above No. 1, as the annexed numbers indicate. It is very remarkable that No. 8 has a mean temperature $0^{\circ}.112$ higher than No. 1, although situated considerably higher. But if we examine its localities more closely, it no longer appears astonishing; for it rises at the foot of the *Drachenfels*, on the eastern side, where the mountain is unusually steep; and if it runs but a few hundred feet in a horizontal direction, or at least in a direction nearer to the horizontal than the slope of the hill, the furthest point of its course may easily lie 100 feet beneath the surface of the mountain. It is, therefore, probable that it rises from a greater depth, in comparison with the mountain, than any one of the rest of the springs; it consequently brings a higher temperature with it from the interior of the mountain, and must be looked upon as thermal, although it certainly does not rise from a greater depth by means of hydrostatic pressure. I will pass over No. 9, because this spring runs for a considerable distance on the surface, and I could not trace it to its source. No. 10 presents a curious phenomenon, namely, when I observed its temperature in December, I found, by plunging the thermometer in at different parts of the little natural basin which it forms, a difference of $0^{\circ}.225$, and remarked that there are two small springs which rise here, scarcely six inches apart, with different temperatures. The lower numbers shew the differences of temperature between the two. I then discovered another spring, No. 11, scarcely three paces distant

from the last, which issued from a cleft in the rock among loose blocks of stone, in a place which was difficult to be got at, and this shewed $1^{\circ}.35$ to $1^{\circ}.575$ lower than No. 10. These three springs rise out of the sandstone of the lignite formation, which is there very much fissured. The comparatively higher temperatures of No. 12 and 14 was no doubt occasioned by both rising from a greater depth, and appearing in deep ravines. The former evidently rises from a greater depth, as may be seen by the motion of the sand at the bottom of the basin. When springs rise in deep ravines from below, they must always appear with a temperature superior to the mean of the place where they issue. All the rest of the springs either run down directly through cracks in the rocks, or at least bear evident signs that they do not rise from below.

If we take all these circumstances into consideration, and compare the mean temperatures with the respective heights, it becomes evident that these mountain springs are by no means capable of giving the decrease of temperature in the soil with the height. If, for instance, we compare the mean temperature of Nos. 3 and 18, we find that the scales of their annual variations are nearly about the same; it may, therefore, be supposed that they both rise from about the same distance below the surface. But, notwithstanding that they seem to be so peculiarly adapted to the determination of the relative decrease of height, yet when we come to examine into it we find it to be exactly the contrary: for the decrease of temperature calculated from this mean is $2^{\circ}.25$ in 428 feet; whereas the same decrease is found, from the direct observations made near *Bonn* and on the *Löwenberg*, to be $2^{\circ}.25$ in 683 feet. It is clear, then, that the spring No. 18, which issues from a cleft in the rock, brings down cold with it from above, and, therefore, does not shew the temperature of the place where it makes its appearance.

Although my endeavours to determine the decrease of temperature with the height, from the mean temperatures of mountain springs, have been unsuccessful, yet we see that the springs in the valley of the *Rhine*, which lie at about the same level, are very well adapted to the determination of the mean temperature of the soil. It is true their mean temperature, $50^{\circ}.22$

TABLE—continued.

	By Inter- polation.		Differ- ence.
	1834	1835	
No. 17.—Spring on the Ausrottweise.			
October 20. . . .	52.929	49.79	3.19
November 8. . . .	49.856	47.75	2.106
December 20. . . .	47.896	45.05	2.85
	1835	1836	
January 10. . . .	47.61	45.05	2.56
June 12. . . .	47.56	45.95	1.613
July 10. . . .	50.45	48.65	1.8
No. 18.—Spring on the Gierscheid's Wiese.	1834	1835	
November 8. . . .	47.18	46.62	0.337
December 20. . . .	46.546	45.95	0.391
	1835	1836	
January 10. . . .	46.35	45.05	1.305
June 12. . . .	45.83	45.16	0.225
July 10. . . .	46.62	45.95	0.675

We here find that the temperatures of these springs in the months of October, November, and December 1835, and January 1836, were altogether lower than during the same months of 1834 and 1835. This lower temperature still shewed itself even in June 1836. In general, these differences all increased as the observations went on, and were greatest in January. But as no observations were made between January and June, it is impossible to decide whether the differences continued to increase still further in the following months. However, the observations in June prove that they afterwards decreased again, and it may be expected that in the following months they will altogether disappear, or perhaps even become negative, if the summer turns out very warm. The maximum differences in the springs Nos. 8, 14, and 18 ($0^{\circ}.99$, $1^{\circ}.26$, and $1^{\circ}.30$), are nearly exactly in proportion to the differences between their yearly maxima and minima ($2^{\circ}.25$, $2^{\circ}.81$, and $3^{\circ}.37$), as given by the above series of observations, from August 1834 to August 1835. In other words, the influence of the external temperature on springs, is smaller, the smaller the yearly variations in the temperature of the springs are, that is to say, the greater the depth from which they rise. However, not one of these springs rises from a depth sufficiently great for the influence of the external temperature to be entirely

without effect. No. 1, the well under the chemical laboratory, alone seems to be no longer affected by it, because its temperature is almost constant. On the 13th June 1836, I found temperature to be the same, $51^{\circ}.23$ as in 1835. Lastly, No. 17, the one which shews the most considerable variations of temperature of all, and therefore takes its rise very near the surface, also shews the greatest differences between the two years; and it is very plain how much it was affected by the cold weather which set in at several periods of the winter of 1835-36.

In order to have a numerical value of the influence of the temperature of the air on that of springs, I subjoin a table of the mean temperatures of the following months of the years 1834, 1835, and 1836, according to the observations of Mr Heis at *Cologne*.

	Mean Temperatures.		Difference.
	1834,	1835,	
June, ...	65.90	64.96	+ 0.92
July, ...	71.60	69.91	+ 1.68
August, ...	68.76	66.70	+ 1.05
September, ...	60.35	61.92	- 1.57
October, ...	52.92	51.35	+ 1.57
November, ...	43.47	38.97	+ 4.5
December, ...	39.87	34.02	+ 5.85
The whole Year, ...	52.58	51.46	+ 1.95
	1835,	1836,	
January, ...	38.75	35.60	+ 3.15
February, ...	41.22	36.72	+ 4.5
March, ...	42.82	46.49	- 3.64
April, ...	49.55	50.22	- 0.675
May, ...	56.11	57.89	- 1.70
June, ...	64.85	67.55	- 2.7
July, ...	70.02	68.9	+ 1.125

The year 1835 was, therefore, with the exception of September, always colder than 1834, and hence the depression of the temperatures of the springs in 1835. The higher temperature in September, was distinctly shewn in the temperatures of the springs in October and November.

Before I had made my own experiments, as above given, on the temperature of mountain springs, I gave myself a great deal of trouble to find out the decrease of temperature in the soil

with the height, from Wahlenberg's single observations on the temperature of the *Swiss Alps*,* von Buch's in the *Canary Islands*,† Forchhammer's on the *Faroë Islands*,‡ and Kern's on the *Swabian Alps*.§ But the results of these attempts were as unsatisfactory as Kämtz's calculations|| on Wahlenberg's observations, which gave the very improbable result, that at a height of 2700 feet, the temperatures of the air and of the soil are equal, but that at the height of 12,000 feet, the soil is 11°.25 warmer than the air.

I have myself observed the temperature of a great number of springs in the Alps; but it would be of no assistance to us, in our present object, to communicate them here. That which resulted from the one year's observations in the *Siebengebirge*, on a small scale, was there seen on a large scale. For example, in the neighbourhood of *Grindelwald*, namely, at the foot of the *Mettenberg* and of the *Eiger*, I observed no less than twenty-two springs, whose temperatures were between 37°.40 50°.00, and the coldest were precisely those which were on the lowest level. What conclusions can be drawn from these on the temperature of the soil, and on the decrease of temperature?

CHAP. XIX.—*What Conclusions may be drawn from the Observations hitherto made on the Increase of Temperature towards the Interior of the Earth?*

In the foregoing chapters we have become acquainted with the various causes which may modify the increase of temperature towards the interior of the earth. Is it then surprising that the results should be so very various, frequently bearing no comparison to each other?

Kircher¶ seems to have been the first who took notice of the

* De Veget. et Clim. in Helvet. septentr., p. lxxvii. § 87.

† Poggendorff's Annal. xii. 407.

‡ Karsten's Archiv für Mineralogie, &c. &c. ii. 199. See also Poggendorff's Annal. xxxv. 213.

§ Kastner's Archiv für Chem. und Meterol. iv. 42.

|| Lehrb. der Meteorol. ii. 200.

¶ Mundus Subterraneus, 1664. fol., vol. ii. p. 184 and 185.

increase of temperature in the earth. The mining officers of *Schemnitz* remarked to him that they had nothing to suffer, either from heat or cold in the mines, so long as there was a good circulation of air; but when such was wanting, it invariably became warmer. From Mr Schapelman, the director of the mines (Bergmeister) at *Herrengrundt* in *Hungary*, Kircher learnt that when the mines are dry, their temperature increases with the depth, because it is impossible, on account of their depth, to give them a sufficient ventilation; but that when they contain water, although deep, they are not so warm. Boerhavé* also mentions the increase of temperature towards the centre, and Mairan† first set up the hypothesis of the existence of fire in the interior of the earth.

Regular observations of temperature in mines began in the middle of the last century, and have been very much multiplied since that time. Either the temperature of the springs, or that of the water which flowed from the adit, was usually observed; but the number of the observations was inconsiderable, and the results are themselves very uncertain, since the waters may bring cold from above or heat from below with them‡; or else they observed the temperature of the air on the rock. We possess observations of this sort in great numbers, and in depths of 1278 feet 11 inches, 1598 feet 8 inches (1200 to 1500 feet French feet?).

The first observations were made towards the middle of the last century in *France*, at the instigation of Mairan,§ in the mines of *Giromagny*, near *Befort*, in the *Vosges*. In the year 1806, D'Aubuisson|| made some observations in the lead and silver mines of *Poullaouen* and *Huetgoët*, in *Bretagne*; and from 1822 to 1825, Cordier¶ did the same, in the coal mines of the departments of *Tarn*, *Nièvre*, and *Calvados*.

From *Switzerland*, we have the observations of De Saussure,**

* *Elementa Chimiæ*, Lipsiæ, 1732, vol. i. p. 403.

† *Mém. de l'Académie pour 1719*.

‡ The former case seems to be the more frequent.

§ *Dissertation sur la glace*, à Paris, 1749, in 12mo, p. 60.

|| *Journ. des Mines*, vol. xxi. p. 60.

¶ *Annal. des Mines*, deuxième série, vol. ii. p. 53-139.

** *Voyages dans les Alpes*, § 1088.

which he made about fifty years ago, in the salt-mines of *Bex*, under very favourable circumstances.

Many observations were also made in *Germany*, namely, in *Saxony*. As, for example, those of Von Freiesleben and Von Humboldt, in the year 1791 ;* those of D'Aubuisson, in 1802 † of Von Trebra in 1805, 1806, 1807, and 1815, ‡ and lastly, those of Von Herder, under the special management of Reich, in the years 1830–1832. § In 1828–1830, regular observations have been carried on in various *Prussian* mining establishments ||

Great Britain has afforded us a great number of observations since 1815 ; namely those of Thos. Lean, Rede, Forbes, and particularly W. Fox and Moyle in the copper and lead mines of *Cornwall* and *Devonshire*, and those of Bald, Dunn, and Fenwick, in the coal-mines in the north of *England*. ¶

In *Sweden* observations were conducted by the director of mines, Claes Wallmann, in the mines of *Fahlun*. ** From *Italy* we have those of Fantonetti, in the gold mines of *Pestarenadi-Macugnana*, † † in the valley of *Anzasca*.

And lastly, we are indebted to Von Humboldt for observations in several of the mines of *Mexico* and *Peru*. ‡ ‡ Complete compilations of these observations, with the exception of those more recently made in *Saxony* and *Prussia*, are to be found in various works. § §

* *Annal. de Chim.*, vol. xiii. p. 210.

† *Description des Mines de Freyberg*, vol. iii. p. 151, 186, and 200, *Journ. des Mines*, vol. xi. p. 517, vol. xiii. p. 113.

‡ *Geogr. Ephemeriden*, 49, 432. *Annal. des Mines*, vol. i. p. 377, vol. iii. p. 59, *Annal. de Chim.* vol. xiii. p. 211.

§ Reich, loco cit.

|| *Poggend. Annal.* vol. xxii. p. 497.

¶ *Annal. de Chim. et de Phys.* vol. xiii. p. 200, vol. xvi. p. 178, vol. xix. p. 438, vol. xxi. p. 308, and *Geogr. Distribution of Plants*, by Winch, p. 51.

* *Kongl. Vetensk. ac Handl. ar* 1831.

† † See Brugnatelli's *Giornale*, 1821, p. 467 ; also Gehler's *neues Phys. Wörterbuch*, vol. iii. p. 978.

‡ ‡ *Annal. de Chim. et de Phys.* vol. xiii. 207.

§ § *Annal. des Mines*, vol. i. p. 378, and vol. iii. p. 63. *Annal. de Chim. et de Phys.* vol. xiii. p. 183. *Gilbert's Annal.* vol. lxxvi. p. 390, very complete. *Gehler's neues Phys. Wörterbuch*, vol. iii. p. 974 and following. Reich, loco citato, p. 139, very complete and comparative.

The following is borrowed from Cordier's comparative results of these observations.

The mean depth in which the temperature rises, $2^{\circ}.25$ F. or 1° R. is, 1st, From the observations of the temperature of the springs; in *Saxony*, 188 feet 7.7 inches (English feet); in *Poullaouen*, 450—10; in *Huetgoët*, 122—6; in *Cornwall*, 102—4; in *Mexico*, 102—4. 2d, From the observations on the temperature of the workings of the mines: in *Cornwall*, 69—3; in *Devonshire*, 110—10; in *Bex*, 106—6.9; in *Poullaouen*, 262—2. 3d, From the observations on the temperature of considerable bodies of water in the mines: in *Cornwall*, 118—4; in *Saxony*, 139—7; in *Huetgoët*, 175—10. 4th, From observations on the temperature of the rock in mines; in *Saxony* 198—3; in *Cornwall*, 69—3 to 122—6.

Cordier's own observations give a mean of 147—10.2 and 61—9.7 feet. As a general result, he asserts that the increase in the internal heat of the earth does not every where follow the same law; that it may be twice or even three times as rapid in one country as in another; that these differences are totally independent of latitude and longitude, and that the increase is certainly greater than has been generally supposed. According to him, an increase of (1° R.) $2^{\circ}.25$ may take place in 61—9.7, or even 53—3.4 feet; but for the present he takes it at 102—3.7. Kupffer* attempts, but with little success, to reconcile the irregularities in these results. Still less can we agree with him, in wishing to determine the mean temperature of the soil from the increase of temperature observed at any particular place.

According to the above-mentioned observations in the mines of *Prussia*, the calculated depth in which the temperature increases $2^{\circ}.25$ F. (1° R.), varies from 63—11.3, 473—5.4 feet.† The latest observations in the *Erzgebirge* also yield very various results; indeed, in the *Neue Hoffnung Gottes* at *Bräunsdorf*, and in the *Stockwerk* at *Altenberg*, the temperature is observed in some cases to decrease. Reich, therefore, calculated the most probable mean from all the results, by taking into consideration, as far as he was able, all the causes which might

* Poggend. Annal. vol. xv. 171. See also Reich, l. c. p. 149.

† Loco citato, p. 528.

have influenced the observations. In this manner he found, for an increase of temperature of $2^{\circ}.25$ F. (1° R.), a depth of 171—6.9 feet. In order to judge of the probability of a constant error, he examined whether the warming or the cooling influences predominated. He found that the error was on the side of the latter, and that the increase of temperature was consequently found too small, which seems also to accord with the observations in other places. Although in several mines observations have been made at more than two points, one below the other, it cannot be determined whether the increase of temperature is proportional to the depth. Sometimes the temperature increases, sometimes decreases with the depth; sometimes it decreases at first, and afterwards increases again, and *vice versa*.

The thermometrical observations hitherto made in mines have, then, given such very various values for the increase of temperature towards the interior, that it is impossible from them to discover the law. This is by no means surprising when we consider how numerous are the causes which tend to discompose that law, and which have been treated of in Chapters IX, XI, XII, to XVII. We have already seen, from the reflections in Chap. XVII. what a considerable influence is due to the configuration of the earth. Some of the observations may have been made in mines excavated on the declivity of steep mountains, in which case, as is shewn in Fig. V, Pl. II, a very protracted increase of temperature would take place. A shaft sunk from *C* to *e*, for example, would have given an increase of $2^{\circ}.25$, $2^{\circ}.65$ — $4^{\circ}.4$ F. (1° R.) in 249 feet, whilst shafts at *c* and *d* would have given 122—6.7 feet. If the configuration of the surface of the earth, at each point of observation, were known, we should be enabled, by means of the formula developed in Chap. XVII., to correct the modifications of the law thereby effected. But how is it possible to bring into calculation the numerous other influences?

However, almost all observations indicate that there exists an inward heat, which is peculiar to the earth itself, which does not proceed from the sun's rays, and increases rapidly with the depth; for the few observations which have given a contrary result cannot be brought forward as proofs against the gene-

rality of this assertion, since local circumstances may sometimes, as, for instance, in the *Sauberg* at *Ehrenfriedersdorf* (see Chap. VI.), cause a decrease of temperature to a certain depth. This may, perhaps, also be the case in the *Swedish* mines.*

Even the most strenuous opponent must be convinced when he considers the high temperature possessed by considerable bodies of water collected in deserted mines. It is impossible to conceive any other cause for this than the innate heat of the walls of the cavities in which the water accumulates. But the temperature of these walls cannot be ascribed to any other cause than the natural high temperature of the earth at a certain depth. Thus, Fox relates that in 1820 the water in the copper and tin mine of *Poldice*, at a depth of 144 fathoms, had a temperature of $79^{\circ}.92$ F., whilst in 1830, when the workings had been carried to a depth of 176 feet, it rose to $99^{\circ}.95$ F.†

A rare opportunity of observing the temperature of an insulated body of water presented itself to Reich.‡ In a mine near *Freyberg*, a supply of water of several cubic feet per minute was cut off, for the sake of prosecuting the works, at a depth of 916—6.7 feet, by means of a *Keilverspündens*. This was composed of wedge-shaped pieces of wood of 6—4.7 feet long, which fitted so exactly together, and against the smooth-hewn walls of the gallery, that, notwithstanding a pressure of 18 atmospheres, a very small quantity of water could escape; on the 20th of March 1833, the escape was only 0.326 cubic feet in an hour. In this manner a space of 62 feet long, 6 feet high, and 3 feet wide, was shut off and filled with water, which had hardly any communication with the gallery. Reich carefully examined the temperature of this body of water on the 30th September 1832, and on the 20th March 1833. These seasons were chosen, because, if the influence of the seasons should be perceptible, it would on these days be the most striking. On the 30th September, he found the temperature of the water, from five perfectly accordant observations, to be $61^{\circ}.65$,

* Bergman, *Physikal-Erdbeschreibung*, 1780-4, vol. ii. p. 118; and Waldmann in Berzelius' *Jahresbericht*, vol. i. p. 149.

† Poggend. *Annal.* vol. xxi. p. 171.

‡ *Loco citato*, p. 134.

and that of the air, 6 fathoms from the *verspünden*, $60^{\circ}.8$ to $61^{\circ}.02$; and on the 20th March, also from five perfectly accor-
dant observations, the temperature of the water $61^{\circ}.56$, and
that of the air, at the same place as before, $60^{\circ}.23$. The dif-
ference of $0^{\circ}.09$ is within the error of observation. It is cer-
tain that the enclosed body of water must have assumed the
temperature of the surrounding rock; and in Reich's opinion
there can be but two causes which could occasion a difference
between them. The first is the escape of some of the water
through the *verspünden*, and its replenishment from above;
the second is the continued change of air before the *verspünden*.
But both of these influences can be but inconsiderable, for, as
we have already remarked, a very small quantity of water
makes its escape, and the enclosed water is separated from the
air by a mass of wood of 6 feet in thickness. Further, these
two circumstances could only tend to diminish the temperature
of the water, as the water was replenished from above, and the
air at the end of the summer, as well as at the end of the win-
ter, was colder than the water, although the difference was
smaller in the former case than in the latter.

From these observations, Reich calculated an increase of
temperature of $2^{\circ}.25$ in 136—11.3 feet, which is very much
more rapid than the mean deduced from the observations in
the mines of the *Erzgebirge*. This adds some weight to the
supposition expressed above, that the mines are by degrees re-
duced in temperature by the entrance of cold air and water
from the surface.

Later observations of Phillips,* in a shaft of unusual depth
recently sunk at *Monk-Wearmouth*, near *Newcastle*, gave re-
sults which corresponded very nearly with those in the *Erzge-
birge*. All external influences could only have caused a depres-
sion, but not an elevation, of temperature in this shaft. With-
out detaining ourselves with the observations on the tempera-
ture of the air and the coal, we will only mention, that that of
the salt-water which collected in a small shaft in the vicinity,
and from which there was an uninterrupted disengagement of
bubbles of carburetted hydrogen, was $72^{\circ}.59$, and when the
disengagement of gas subsided, $72^{\circ}.0$ and $71^{\circ}.60$. The mouth

* Philosophical Magazine, 1834, vol. v. p. 446.

of the shaft lies 86—10.2 feet above the flood-mark of the sea ; the point of Phillips's observations 1584—0.8 feet below the opening of the shaft, and consequently 1497—0.6 feet below the surface of the sea. At the upper end of the shaft, the mean temperature of the air was $47^{\circ}.58$, and that of the salt-water below $72^{\circ}.59$. Supposing the temperature not to have increased in the last 100 feet (?), so that $72^{\circ}.59$ were the temperature at the depth of 1484—0.7 feet, Philips calculates an increase of $2^{\circ}.25$ F. (1° R.) in a depth of 133—6.8 feet.

These observations point out in what manner the most accurate results as to the increase of temperature towards the centre of the earth are to be obtained. In old exhausted mines galleries are often to be found in which water might probably be shut off in a similar manner for the sake of observations, as was done in the *Freyberg* mine above referred to. Although the expense of the observations would be increased by such operations, yet, on the other hand, they would be very much simplified, as it would be sufficient to make them *twice* a-year, in spring and autumn.

Another very favourable opportunity of obtaining accurate thermometrical observations offered itself in the sounding at *Pregny* near *Geneva*, already referred to more than once.

Mr Giroud wished to have an artesian well sunk at his country seat at *Pregny*. On coming to a depth of 582—11.7 feet, without meeting with water, he gave up the undertaking. Messrs de la Rive and Marcet upon this opened a subscription for the continuation of the work, and thus they succeeded in reaching a depth of 726—10.2 feet. The failure of the first object of the undertaking, namely, to obtain spring water, was particularly favourable to the observations, as the variations of temperature, caused by the gushing in of water into the well, were thereby entirely avoided. The water in the well rose once to within 13—10.2 feet of the surface ; at 106—6.9 to 159—10.3 feet deep it was so muddy that no such influx of water could possibly have been supposed to exist, especially near the bottom it was rather a very wet earth than water. The prejudicial effects of currents of air in dry wells were consequently also prevented. Besides which the thermometer was enclosed in a cylinder of $4\frac{1}{2}$ inches in diameter, which exactly fitted into the well, so that, at least, whilst it was sunk to any certain

depth for ascertaining the temperature, all possible influx of water was prevented. Lastly, the fact that the results obtained at a certain depth exactly coincided, whether observed at the bottom of the well or at the same point afterwards, when the work had been carried on to 106—6.9, 213—1.8, or 319—8.7 feet below that point, puts it beyond doubt that nothing could have tended to disturb the observations.

The temperature was observed with the utmost care by means of a maximum thermometer. The results shewed so exact a coincidence among each other, as well as with those of a common thermometer in the less considerable depths, that the greatest confidence may be placed in them. The following includes the whole series:—

FIRST SERIES.		SECOND SERIES.	
Depth below the surface.	Corresponding Temperatures.	Depth below the surface.	Corresponding Temperatures.
Feet.	Fahr.	Feet.	Fahr.
31—11.7	50.9	319—8.7	
63—11.3	51.12	63—11.3	
106—6.9	51.8	106—6.9	51.57
159—10.3	52.47	151—4.1	52.43
213—1.8	53.37	213—1.8	53.15
266—5.2	54.50	266—5.2	56.97
319—8.7	55.62	319—8.7	55.51
373—0.1	56.52	351—8.4	55.96
426—3.7	57.57	373—0.1	56.52
479—7.1	58.38	394—3.9	56.75
532—10.6	59.45	426—3.7	57.31
586—2.	60.41	458—3.4	57.87
639—5.5	61.36	479—7.1	58.32
692—8.9	62.37	532—10.6	59.56
724—8.6	63.05	586—2.	60.45
		638—4.6	61.47
		692—8.9	62.59

In the first series the thermometer remained in each station so long as was found necessary by experience for the exact observation of the temperature.

The second series was undertaken in order to ascertain whether, by sinking the thermometer more or less rapidly, any difference in the results would ensue from the heat caused by the friction of the metallic cylinder against the sides of the well. However the presence of the water would lead us to expect a negative answer to this question.

From the above observations we find that from 106—6.9 feet (to which depth the temperature remains constant at $51^{\circ}.68$) to 724—8.6 feet deep, the temperature increases in direct proportion to the depth, and that the increase of depth corresponding to each additional degree of Reaumur is 122—2.8 feet. There is no doubt that this regularity in the increase of temperature is owing to the place of observation being perfectly free from all causes of disturbance. As former observations in other places have generally shewn great irregularities in the increase of temperature, it is probable that they have been influenced by accidental circumstances.

The lowest degree observed, $50^{\circ}.9$, still exceeds by $1^{\circ}.35$, the mean temperature of *Geneva* ($49^{\circ}.55$). De la Rive and Marcet are of opinion that they would have found this last in a depth of 42—7.6 to 53—3.5 feet, if they had been able to penetrate into the rock itself. They think that the higher temperature of the water in the upper part of the well must be ascribed to currents of water which brought up heat from below, and which seemed probable from the clearness of the above. The influence can, however, only have extended to the first 106—6.9 feet.

CHAP. XX.—*Can the Progression of the Increase of Temperature towards the centre of the Earth be with certainty deduced from the Temperature of Artesian Springs, and the depth from which they rise?*

Arago long ago declared that artesian wells were peculiarly adapted to the determination of the rate of increase of temperature in the earth. More lately Spasky* and Kupffer† have endeavoured to calculate that rate from existing observations.

In order that such a calculation should yield accurate results, it is necessary that the following conditions should take place:—1st, That the spring should not rise from below the place of its first appearance in the well; and, 2d, That it should also have exactly the temperature of the lowest point of the well.

If the well have been sunk to within a short distance of an impervious stratum, the first condition will easily be fulfilled. But if it happen to have encountered a spring, coming from

* Poggend, Annal. vol. xxxi. p. 365.

† Ibid. vol. xxxii. p. 284.

below, under a pressure sufficient to force it to the surface, the temperature of the well cannot be the same as that of the rock at the bottom. And even if the lowest point of the course of such a spring were exactly on the same level as the bottom of the well, yet it could only assume the temperature of the surrounding rock, in case it should have remained long in contact with it. This may, with probability, be supposed to be the case, when the temperature of the spring is constant. However, it may also take place, even though its temperature be variable, if its variations follow late after those of the air. So that the later in the year a spring reaches its maximum temperature, the more likely it is to shew the true temperature of the lowest point of its course.

On the contrary, springs whose variations of temperature take place nearly or exactly at the same time as those of the atmosphere, will not give the real temperature of the lowest point of their course. Thus, the salt-springs of *Werl* can hardly be expected to shew the real temperature of the lowest point of their course, as their variations of temperature correspond almost exactly with those of the air.*

Spasky and Kupffer calculated, from the observations on the temperature of the artesian wells at *Vienna*,† an increase of temperature of 1° R. or $2^{\circ}.25$ in 88—5.5 and 83—1.5 feet. Kupffer found the same at 80—11.9 and 74.7.2 feet from those of *Rochelle* and *Epinay*.‡ From Mr Griffith's § observations on the temperature of two springs encountered at different depths, it was calculated at 49.0.3 feet.

So rapid an increase of temperature gives room for the conjecture, that the depths of all these wells are not equal to the lowest point of the course of the springs, but that the springs rise from a still greater depth.

* These thermal springs indicate the immediate influence of the external temperature, which is certainly not communicated through the earth. Their yearly mean temperature, however, coincides nearly with the temperature of the earth at the lowest point of their course. In so far it might offer a numerical element for the calculation of the increase of temperature with the depth, provided the well were as deep as the lowest point of the spring's course.

† Baumgärtner Journ. für Phys. und Mathem., vol. viii. No. 3.

‡ Journ. de Geologie. 1830. Vol. i. p. 89.

§ Ibidem, p. 87.

Handwritten text block, likely a list or index, with several lines of text.

Handwritten text block, continuing the list or index.

Handwritten text	Handwritten text
Handwritten text	Handwritten text
Handwritten text	Handwritten text
Handwritten text	Handwritten text
Handwritten text	Handwritten text
Handwritten text	Handwritten text
Handwritten text	Handwritten text
Handwritten text	Handwritten text

Handwritten text block, likely a list or index, with several lines of text.

Handwritten text block, likely a list or index, with several lines of text.

Handwritten text block, likely a list or index, with several lines of text.

Handwritten text block, likely a list or index, with several lines of text.

sition. The position of this shaft is such, that the circumstances must be supposed rather to resemble those at *Geneva* and *Rüdersdorf*, than those in the *Erzgebirge*; but they in so far resemble those of the *Erzgebirge*, that the influence of the atmosphere, as Phillips remarks, can only cause a depression, but not an elevation of temperature.

However improbable, therefore, it may be, that perceptibly different values should be found for n beneath plains and in mountains, it would yet be desirable that such favourable circumstances as those at *Geneva*, in the *Erzgebirge*, and in the *English mines*, should be more frequently met with and taken advantage of. Then it would not be long before a general law for the increase of temperature towards the centre of the earth would be found. And if this law should suffer interruptions, as all other physical laws do, yet a numerical expression for such interruptions might possibly be discovered.

The following Table is illustrative of the observations in Chapter VI. of this article, at p. 362 of the 20th volume of this Journal.

TABLE—Temperatures of Springs.

	1	2	3	4	5	6	7	8	9	10
	Obakälla in Wärmland.	Lassbybackar, near Upsala.	Ditto.	Källsprohng, near Lassbybackar.	Möhl spring, near Upsala.	Brennerel Spring, near Upsala.	Ditto.	Ditto.	Professors Spring, near Haga.	Ditto.
Years.		1809 1810	1810 1811	1809	1809 1810	1808 1809	1809 1810		1809	1810
January,	°	36°.86	36°.05	°	43°.79	44°.06	43°.88	°	°	41°.41
February,		35.91			43.79	44.24	43.79			40.39
March,		34.88	34.25		43.79 (1811)	43.88	43.79	43.70		39.72
April,		34.15	33.84		43.60		43.52			38.52
May,		35.08	33.84	44.05	43.70	44.06	43.61	43.70		38.68
June,		42.66				43.97				40.36
July,	41.18					44.06				
August,	41.00	54.50		54.68	44.05	44.24	43.70			46.04
September,	41.00	52.51		55.84		44.24	43.88		48.65	46.40
October,		46.80		50.78		44.06	43.88		47.6	46.57
November,		42.14	40.77		43.88	44.06	43.88		44.64	
December,		37.98	37.94			44.24	43.79		42.35	
Mean,	41.06	41.71			43.85	44.098	43.77	43.70	42.26	41.9
Differ. between Max. and Min.	0.18	20.34			0.45	0.36	0.36		6.3	7.2

TABLE—continued.

	12	13	14	15	16	17	18	19	20	21	22
	Near Haga.	Priester Spring, near Haga.	Gnesta Windmühle, on the road to Fundbo.	Norbygard in Bondkyrka John.	Norbylund.	Mybygard in Dan- marksöcken.	Staby Spring in Narsöcken.	In the neighbour- hood of Colinton, near Edinburgh.	Ditto.	Königsberg in Prussia.	Louisen Syring near Berlin.
cars.	1809 1810	1809 1810	1810 1811	1809 1810	1810 1811	1810		1827 1828	1827 1828		1811 1812
uary.	43.52	"	"	42.98	"	"	"	50.85	49.19	45.02	49.45
uary,	43.34			42.8				49.30	46.06	44.19	49.10
ch, .			42.26	42.8				49.88	48.67	43.74	49.10
		(1811)		(1811)							
l, .	42.08	43.34	42.26	42.8	42.26			49.34	49.34	44.73	48.91
, . .	42.08	43.70	42.53	42.8	42.8	43.15		50.31	51.89	45.18	
, . .				42.8			43.57	52.54	55.19	46.58*	
st, .	43.15	43.88	42.8	42.98	43.60	43.15		53.55	56.46	48.01*	
ember,	43.88	43.88	43.15	43.34		43.34	43.70	53.05	55.75	49.23*	49.45
		44.24						52.32	54.81	49.77*	49.45
ber,		44.05	43.43			43.34		52.38	53.71	49.41	49.45
ember,		43.92						51.75	50.13	47.97	
ember,	43.52							51.41	49.30	46.53	49.45
, .	42.98	43.96	42.98	42.93	43.20	43.25		51.39	51.70	46.85	49.30
r. be- Max. Min. }	1.8	0.9	1.17	0.54				4.25	10.39	6.03	0.54

	23	24	25	26	27	28	29	30	31	32	33
	On Ravensberg, between Bergholz and Langerwisch.	Telkover Vorstadt, near Potsdam.	Ditto.	Near the Hayel, between Potsdam and Templin.	Ditto.	Templin, near Potsdam.	Ditto.	Mineral Springs at Meinberg.			
								Trinkquelle.	Neubrunnen.	In Stern.	Schwefelquelle.
cars.		1814 1819	1819	1817 1819	1819	1814 1819	1819	1830 1831	1830 1832	1830 1832	1830 1832
uary.	50.00	44.57	44.05	49.48	49.41	47.84	47.48	"	"	"	"
uary,	50.00	45.09	44.97	49.48	49.48	48.88	47.88	44.37	44.37	41.56	38.32
ch, .	50.00	46.28	46.28	49.45	49.32	48.42	48.35	44.52	44.37	42.12	
l, .	50.09	47.88	47.88	50.11	50.22	48.65	48.53	45.50	44.37	42.12	38.75
, .	50.00	51.75	51.98	50.31	50.45	49.66	49.55	46.62	46.62		48.87
e, .	50.09	53.78	55.06	50.67	50.78	50.58	50.56				
, .	50.09	55.53	57.46	50.90	50.90	50.56	50.56				
st, .	50.22	56.07	57.42	51.23	51.68	50.78	51.10	54.27	55.96	53.37	61.25
ember,		53.43	53.43	51.12	51.12	50.56	50.56				
ober,	50.18	52.25	50.9	50.26	50.00	49.73	49.68				
ember,	50.09	48.57	48.08	49.45	49.36	49.34	49.32				
ember,	50.00	45.18	43.92	49.45	49.43	48.17	48.20				
n, .	50.07	50.22	50.11	50.16*	50.18	49.34*	49.32	47.41	47.54	44.15	44.01
er. be- n Max. Min. }	0.225	11.49	13.54	1.77	2.27	2.94	3.62	10.12	11.58	11.81	22.92

TABLE—continued.

	34	35	36	37	38	39	40	41	42	43
	Salt Springs at Werl.									
	Michael's	Shaft.	Bore.	Hofes.	Maximilian.	Shaft.	Well in Düsseldorf.	Queckbrunnen, near Burgbrohl.	Ditto.	Mineral Spring near Burgbrohl, No. 1.
Years.	1832	1833	1832	1833	1832	1833	1831	1833	1834	1833
January,	°	44.66	°	49.23	°	54.20	47.52	°	(1835) 49.10	°
February,		47.75		50.00		53.03	47.30		(1835) 48.42	
March,	46.03	47.22	50.49	50.18	53.08	52.79	47.86		48.65	
April,	51.46	48.85	52.65	52.10	54.74	55.37	47.88	45.95	46.62	52.70
May,	53.26	51.21	53.17	55.04	53.82	56.32	48.06	46.85	46.85	52.92
June,	52.90	52.92	57.45	55.51	54.70	55.51	49.75	47.75	47.52	53.37
July,	53.64	53.91	54.85	55.92	55.21	57.31	50.63	48.46	48.65	53.60
August,	53.60	53.62	54.87	54.57	55.17	56.75	51.42	48.87	49.10	53.37
September,	53.15	52.70	54.59	55.40	54.83	55.85	52.33	49.32	50.00	53.48
October,	51.44	52.51	52.70	54.95	55.44	52.62	53.33	49.70	50.90	53.37
November,	48.87	51.12	50.42	53.95	50.06	49.66	50.99		50.45	
December,	46.26	48.20	50.13	53.10	52.25	52.51	48.42	48.87	49.77	58.15
Mean,	51.15	50.38	52.60	53.48	53.71	54.32	49.66	48.22	48.65	53.24
Differ. between Max. and Min.	7.15	9.24	4.74	6.63	2.96	4.52	6.03	3.80	4.50	0.9

	45	46	47	48	49	50	51	52	53	54
	Fresh Springs at Basel.									
	Mineral Spring near Burgbrohl, No. 2.	Ditto.	Mineral Spring near Burgbrohl, No. 3.	Ditto.	Mineral Spring at Tönnistein.	Hottest spring at Bartscheid.	Lochbrunnen at the Herbrüggen.	Lochbrunnen, near the Post-office.	Well behind the School.	Corn-market Well.
Years.	1833	1834	1833	1834	1835	1833 1834	1821	1821	1821	1821
January,	°	°	°	°	°	159.35	44.95	47.65	48.01	47.65
February,						159.8	42.8	46.40	47.11	46.75
March,		57.65		56.30		160.25	42.8	47.11	47.48	47.30
April,	57.87	57.31				160.13	43.51	48.01	48.20	48.20
May,	57.87		57.76		55.40	160.70	43.65	48.01	48.38	48.38
June,	58.10	58.10		57.65		160.70	47.46	49.45	48.74	48.91
July,	58.10	58.10	57.98	60.35	55.40		48.74	49.81	49.28	49.45
August,	58.10	58.21	57.65		55.17	159.57	50.18	50.18	49.68	49.81
September,	58.10	58.21	57.53	57.42	55.17	158.22	52.51	51.98	51.8	51.44
October,	58.10		57.20		54.95	158.22	52.34	50.90	50.9	50.90
November,						158.67	50.00	49.45	49.68	50.64
December,	58.10					158.9	49.55	49.45	49.45	49.45
Mean,	58.05	57.91	57.63	57.91	55.21	159.51	47.62	49.12	49.05	58.95
Differ. between Max. and Min.	0.225	0.90	0.79	4.05	0.45	2.47	9.71	5.53	4.68	4.68

TABLE—continued.

	56	57	58	59	60	61	62	63	64	65
	Fresh Springs at Basel.			Stuttgart.						
	Biblm's Well.	St Alban Thal Well.	Well on the Münsterplatz.	Temperature of the spring.	Temperature of the air.	Temperature of the spring.	Temperature of the air.	Temperature of the spring.	Temperature of the air.	Temperature of the spring.
Years.	1821.	1821	1821	1828	1829	1829	1829	1830	1830	1831
January,	47.65	50.00	46.40	43.02	37.17	38.84	24.69	34.77	15.8	37.98
February,	46.94	50.00	44.60	42.25	35.24	36.36	28.72	34.77	27.89	37.47
March,	46.04	49.45	46.21	43.74	42.25	38.67	39.62	37.75	44.57	42.16
April,	46.75	49.81	47.84	47.97	50.76	45.95	50.58	47.30	54.18	48.15
May,	48.20	49.28	49.64	53.64	60.39	52.37	53.12	53.60	60.72	52.40
June,	49.45	49.81	50.35	58.47	65.72	57.35	62.09	56.77	62.71	56.50
July,	50.00	49.64	52.51	62.09	68.9	61.38	67.84	60.30	69.19	61.02
August,	51.43	50.00	53.60	60.39	63.27	61.47	63.25	61.43	65.79	61.67
September,	53.60	51.08	54.31	59.04	59.22	58.17	55.73	57.29	55.89	57.76
October,	53.24	51.25	52.88	54.52	48.83	52.45	46.37	53.48	48.10	55.98
November,	51.43	50.90	49.28	47.00	40.90	44.73	34.76	48.06	43.27	48.83
December,	50.00	50.58	48.20	42.91	37.44	38.70	21.52	41.22	33.14	44.10
Mean,	49.57	50.13	49.66	49.10	51.68	48.87	46.73	51.44	48.42	50.34
Extr. between Max. & Min.	7.53	1.8	9.72	19.93	33.66	25.11	43.15	26.95	53.39	24.21

	66	67	68	69	70	71	72	73	74	75
	Stuttgart.							Tübingen, temperature of the spring.	Ditto.	Ditto.
	Temperature of the air.	Temperature of the spring.	Temperature of the air.	Temperature of the spring.	Temperature of the air.	Monthly mean temperature of this spring.	Monthly mean temperature of the air.			
Years.	1831	1832	1832	1833	1833			1831	1832	1832
January,	26.7	39.32	30.43	36.05	24.44	38.39	26.85	39.87	42.68	35.52
February,	38.50	39.42	33.95	36.68	35.71	37.78	33.22	39.87	41.56	38.88
March,	44.71	40.55	39.49	39.58	37.58	40.41	41.56	43.51	43.38	43.11
April,	52.56	47.02	49.84	43.94	46.60	46.62	50.79	48.33	48.01	46.26
May,	58.45	51.75	56.61	54.68	66.08	53.05	56.34	52.51	52.38	53.07
June,	63.27	57.20	62.24	60.08	68.20	57.72	64.06	56.41	56.25	59.13
July,	68.00	61.67	66.10	60.93	63.54	61.25	67.30	58.21	59.26	56.32
August,	65.56	63.38	67.47	58.93	59.47	61.20	64.13	60.12	61.38	55.49
September,	56.52	58.55	56.75	55.51	56.07	57.85	56.70	56.75	56.61	55.32
October,	56.67	53.90	48.35	52.49	47.79	53.80	49.34	55.06	50.40	52.08
November,	41.58	46.02	38.07	46.80	40.95	46.98	39.91	49.70	44.24	49.01
December,	47.64	40.02	34.92	44.28	41.97	41.9	34.43	45.36	40.28	46.09
Mean,	51.01	48.60	48.85	49.23	49.14	49.73	49.30	50.47	49.68	49.23
Extr. between Max. & Min.	39.44	23.96	37.05	24.88	43.76	23.47	40.45	20.25	19.82	23.60

198 Prof. Bischof on Hot and Thermal Springs.

No. 1—18, Wahlenberg, Gilbert's Annal. v. xli. p. 113. and fol.

No. 19 and 20, Berghaus's Hertha, Jan. 1829, v. xiii. p. 20. Spring 19 rises out of a bed of pyrites, and is situated 337 feet above the level of the sea. No. 20, which rises out of clay, lies 264 feet above the sea.

No. 21, Erman jun., Poggend. Ann. v. xi. p. 297 and fol. The temperatures signed * are found by the interpolation.

No. 22, Wahlenberg, loco cit. p. 160. Erman sen. (see Abhandlungen der Kön. Acad. d. W. in Berlin for 1818—1819, p. 377 and fol.) observes that Wahlenberg's scale of variations in the temperature of this spring remained the same during several years. According to him its mean is $45^{\circ}.66$.

No. 23—29, Erman sen. as above.

No. 30—33, Brandes die Mineralquellen, &c. zu Meinberg, Lemgo 1832, p. 271, 293, 306, and 317.

No. 34—39, communicated by M. v. Lilien, Director of the Salt Works at Werl.

No. 40, communicated by Prof. Benzenberg in Dusseldorf.

No. 41—49, observ. of the author.

No. 50, communicated by M. Wagner, Surveyor of Aix-la-Chapelle.

No. 51—58, Abhandlung über die Wärme der Erde in Basel, von Merian. Basel, 1823.

No. 59—75, According to the communication of Prof. Pleninger in Stuttgart.*

* For the reductions of the degrees to the scale of Fahrenheit in the Memoir of Bischof, I am indebted to Mr George Atkin, author of the useful Thermometrical and Barometrical Tables, published by Messrs A. & C. Black, Edinburgh.

ON THE
NATURAL HISTORY OF VOLCANOS AND
EARTHQUAKES.

PART III.

Are volcanic phenomena capable of a satisfactory explanation from the increase of temperature towards the centre of the earth, or can chemical processes be admitted with greater probability to be the cause of volcanic action ?

ON inquiring into the cause of volcanic phenomena we must not forget, says Von Humboldt,* that the arrangement of volcanos sometimes in circular groups and sometimes in double lines, is the most decided proof that their action is not dependent on any trifling causes, lying near the surface, but that they are vast and deeply-seated phenomena. Thus, for example, the whole of the high country of *Quito* is one volcanic hearth, of which the mountains of *Pichincha*, *Cotopaxi*, and *Tunguragua*, form the summits. The subterranean fire breaks out sometimes from one sometimes from another of these vents, which are usually considered as distinct volcanos. The earthquakes, with which *America* is so dreadfully visited, are also remarkable proofs of the existence of subterranean communications, not only between countries free from volcanos, as has been long known, but also between volcanic hearths situated at a great distance from each other. All these circumstances prove that the forces do not act at the surface of the crust of the earth, but that, proceeding

* On the structure and action of volcanos in various parts of the earth, in the *Abhandlungen der Königl. Acad. d. Wissensch. zu Berlin*, 1822 and 1823, p. 137, and in Jameson's *Phil. Jour.* vol. v. p. 222.

from the interior of our planet, they communicate contemporaneously by fissures with the most distant points on the surface.*

Two hypotheses may be proposed respecting the causes of volcanic phenomena. The one supposes them to be occasioned by intense chemical actions taking place between bodies having a very great affinity to each other, and by which so great a heat is produced, that lavas melt and are forced to the surface of the earth by the pressure of elastic fluids. According to the other, the earth at a certain depth is at a white heat, and this heat is the chief cause of volcanic phenomena

CHAP. XXI.—*The hypothesis, which ascribes volcanic phenomena to intense chemical action, shewn to be untenable.*

We will not detain our readers with an account of the earlier hypotheses, which derive volcanic phenomena from the action of iron upon sulphur, or from the combustion of pyrites or coal, as their insufficiency is self evident. But Davy's discovery of the metallic bases of the alkalies and earths was considered as throwing a great light on this subject.

This distinguished philosopher, who instituted some very interesting experiments at *Vesuvius* during its eruptions in 1814, 1815, 1819, and 1820, endeavoured to explain the phenomena by the oxidation of the metals of the alkalies and earths.† He thinks himself justified in supposing the caverns beneath the *Solfatara* of *Puzzuoli* to have a subterranean communication with *Vesuvius*, because whenever the latter is in action, the former is in repose. A slip of paper which Davy threw into the mouth of the *Solfatara*, during an eruption of *Vesuvius*, was not rejected, from which he concluded that there must be a descending current of air. The subterranean thunder, which is heard at such great distances from beneath *Vesuvius*, seems to him to indicate the existence of great

* Von Humboldt's *Reisen in die Äquinoctial Gegenden des neuen Continents*, t. i. p. 496, t. iii. p. 24, 26, and 40, offer many instances of this kind.

† Sur les Phénomènes des Volcans. *Annales de Chim. et de Phys.* vol. xxxvii. p. 133.

subterranean caverns, filled with gaseous substances, and that the same caverns which, during the activity of the volcano, continue for a long time to eject enormous quantities of aqueous vapour, must be filled, during its repose, with atmospheric air. In proof of the existence of extensive caverns, he mentions those in the limestone of Carniola. Now, as the metals of the earths in the supposed volcanic caverns are not only exposed to the action of the air but also to that of aqueous vapour, they will be oxidized at the expense of both, and be converted into lava. He thinks his hypothesis capable of explaining all the phenomena which he observed.

Davy also touches upon the circumstance, often mentioned by geologists, that almost all great volcanos are situated near the sea.* Supposing their first eruption to have been caused by the action of the sea-water upon the metals of the earths, and the metallic oxides, ejected from the craters in the form of lava, to have left vast caverns, the succeeding eruptions would be effected by the oxidations which would ensue in those caverns. Davy is of opinion that when volcanos lie at a distance from the sea, as those of *South America*, the water may be furnished from subterranean lakes; for Von Humboldt asserts† that some of these volcanos cast up fish.

If we wish to ascribe volcanic phenomena to chemical action, says Davy, the oxidation of the metals of the earths and alkalis merit our attention in preference to any other process. He himself, however, observes, that the observations in mines and in hot springs seem to indicate, with some degree of probability, that the interior of the earth possesses a very high temperature, and that, if the earth's nucleus be supposed in a state of

* That volcanos may act at a great distance from the sea is proved by the *Peskan* in the centre of *Asia*, which is 260 geographical miles distant from any great sea, and from which streams of lava have issued within the period of our history. Even the opinion that the vicinity of extensive lakes operates on the volcanos of *Central Asia*, in the same manner as the ocean, is unfounded. The volcano of *Turfan* is surrounded by very inconsiderable lakes, and the lake of *Temartu* or *Tsikul*, which is not twice as large as the *Lake of Geneva*, lies fully 25 geographical miles from *Peskan*. See also Girardin in opposition to Davy's hypothesis in Jameson's *Phil. Journ.* vol. ix. p. 136.

fusion, the explanation of volcanic phenomena is simpler than according to his own theory.

Gay Lussac very justly remarks, that it is impossible to conceive the admission of atmospheric air into the focus of volcanos, as there must be a force within them acting outwards, by which the liquid lava, a substance about three times as heavy as water, is raised to a height of above 3000 feet, as at *Vesuvius*, and more than 9000 feet in many other volcanos. A pressure of 3000 feet of lava, equal to that of a column of water of 9000 feet high, or to about 300 atmospheres, necessarily prevents the entrance of air into the interior of the volcanos; and as this pressure continues for many years, during which time the phenomena by no means abate in activity, it is impossible that air should in any way contribute to it.

The presence of water in volcanos during the various stages of their activity is, on the other hand, a circumstance repeatedly witnessed by all observers.* Even the smoking during their intervals of repose is, for the most part, nothing but a disengagement of aqueous vapour. Violent eruptions are not unfrequently followed by such enormous quantities of steam, that it condenses in the atmosphere, and falls in heavy showers, as was the case after the memorable eruption of *Vesuvius*, which destroyed *Torre del Greco* in 1794.† Among the elastic fluids evolved from volcanos, besides aqueous vapour, we frequently find sulphureted hydrogen gas, as, for example, from those at the equator; and from others, as *Vesuvius*, muriatic acid gas. But the formation of these gases in the interior of volcanos cannot be conceived without the presence of water.

If the oxidation of the earthy and alkaline metals were to take place at the expense of water, enormous quantities of hydrogen would be necessarily evolved during volcanic eruptions. But this gas seems never to issue from volcanos. According to the

* See, among others, Monticelli and Covelli, der Vesuv. Deutsch bearbeitet von Nöggerath and Pauls. Elberfeld, 1824, p. 157.

† See von Buch's geognostische Beobachtungen, tom. ii. 152. There is, however, still another cause, which occasions these heavy showers, as we shall shew afterwards.

observations of Breislak,* Spallanzani,† Monticelli and Covelli, ‡ Hoffmann, § and Poulett Scrope, || flames are never seen to rise from the crater of *Vesuvius*. Neither did Gay-Lussac¶ during his stay at *Naples* in 1805, during which he was a frequent witness of explosions, which raised the fluid lava to a height of above 600 feet, ever observe a combustion of hydrogen gas. Each explosion was accompanied with dense black columns of smoke, which would have inflamed, had they been composed of hydrogen gas, as they were traversed by bright red-hot masses. According to Boussingault, neither hydrogen, muriatic acid gas, nor nitrogen gas, is evolved from the volcanos, under the equator, in the New World.** In opposition to this evidence, we have the assertions of Von Buch. ††

Davy's hypothesis does not account for the exhalations of carbonic acid gas (Mofettes), which not only succeed every eruption of *Vesuvius*, but also occur in the vicinity of extinct volcanos and in places affording unquestionable traces of former volcanic action (*Auvergne, Vivarais, Eifel, Laacher See, Bohemia*, and so forth,) ‡‡ in amazing quantities, and as far as we can learn from history, with uninterrupted uniformity. These phenomena must necessarily be closely connected with volcanic action, and cannot pass unnoticed.

But these disengagements of carbonic acid gas could not take place in the presence of atmospheric air in those vast subterranean cavities without their mixing together. Yet, according to Monticelli and Covelli,||| the Mofettes of *Vesuvius* con-

* Lehrbuch der Geologie, transl. into German by Strombeck, vol. iii. p. 117.

† Voyages dans les Deux Siciles etc. vol. ii. p. 31.

‡ Loco cit. p. 191.

§ A personal communication.

|| Considerations on Volcanos. London 1825.

¶ Loco cit. p. 420.

** Anal. de Chim. et de Phys. t. lii. p. 23.

†† Loco cit. t. ii. p. 141.

‡‡ Monticelli and Covelli, l. c. p. 191. Bischof and Nöggerath in Schweigger's Journ. v. xliii. p. 28. Bischof in Schweigger-Seidel's Journ. v. xxvi. p. 129. The same in his Vulkanischen Mineralquellen. Bonn. 1826, p. 251. Von Buch in Poggendorff's Ann. v. xii. p. 418.

||| Loco cit. p. 194.

tain but little atmospheric air, which seems not to intermix with the carbonic acid gas until it reaches the surface. I have examined many such exhalations of carbonic acid gas, in the vicinity of extinct volcanos (in the neighbourhood of the *Laacher See* and in the *Eifel*) as well as in places where there are no immediate volcanic traces (*Hundsrück*, the eastern declivity of the *Teutoburger Wald*), and, in general, have found a scarcely measurable quantity of atmospheric air. According to Bous-singault,* the elastic fluids, which are evolved from the volcanos at the equator in the New World, consist of a great quantity of aqueous vapour, carbonic acid gas, sulphureted hydrogen gas, and sometimes fumes of sulphur; he considers sulphurous acid gas and nitrogen, on the other hand, as accidental. This philosopher† also found the same gases, viz., carbonic acid and sulphureted hydrogen gas, in the springs which rise in the vicinity of these volcanos. All this is by no means favourable to the supposition of the existence of vast subterranean cavities filled with air under the craters, and an equally unfavourable circumstance is, that, according to Bous-singault, no nitrogen is evolved from the volcanos under the equator, which must necessarily be the consequence of oxidation at the expense of atmospheric air.

Independently of all this, the metals of the earths have been found by more recent experiments to be by no means so easy of oxidation as Davy's hypothesis assumed. Besides, this proneness to oxidation must be supposed to be a property more especially belonging to the metals of silica and alumina, as these earths together with oxide of iron, are the principal components of volcanic products,—lavas, basalts, &c., generally amounting to about 0.8, whilst lime and alkalies, although never entirely wanting, form but an inconsiderable proportion. But Berzelius‡ has shewn, that silicium, the combustible base of silica, when freed of hydrogen by being gradually heated to a white heat, is incombustible even at that heat in the air or in oxygen; and that it is equally incapable of decomposing water. In like manner Wöhler§ found, that aluminum, the metallic base of

* *Loco cit.* v. lii. p. 5.

† *Poggend. Ann.* v. i. p. 221.

† *Ibid.* p. 181.

§ *Ibid.* t. xi. p. 146.

alumina, is not oxidized under a red heat, and decomposes hot water but very slowly, while on cold water it has no influence whatever.

Therefore Davy's hypothesis would be applicable only to the metallic bases of alkaline earths and alkalis. But, as these occur only in small proportions in the volcanic rocks, it is scarcely conceivable that so much heat should be evolved by their combustion at the ordinary temperature as would be sufficient to melt the pure earths, or to inflame their metals, supposing them to exist at the seat of the volcanic action.

The slight specific gravity of the metals of the alkalis, also proves fatal to Davy's hypothesis; for, if the mean density of the earth surpass that of all kinds of rocks, those metals cannot exist, at least not in great quantities, in the interior of the earth.* Davy's hypothesis, therefore, according to the present state of science, will not account for volcanic phenomena.†

Gay-Lussac,‡ assuming that water supplied the oxygen in volcanos, endeavoured to account for the absence of uncombined hydrogen among the exhalations of volcanos, by supposing it to form such combinations with other bodies as would not inflame by coming into contact with the air. This is the case when it combines with chlorine to form muriatic acid gas. He here refers to the observations of Breislak,§ and of Monticelli and Covelli||, which shew that this acid is among the exhalations of volcanos. He himself, however, observes, that an enormous quantity of muriatic acid must be evolved from the craters, if the hydrogen, which would result from an oxida-

* Also the latest experiments, made with admirable exactness by Professor Reich in *Freiberg*, with the assistance of the torsion-balance, have given 5.44 for the density of the earth, as a mean of 14 experiments which afforded very nearly the same results. *Versuche über die mittlere Dichtigkeit der Erde mittelst der Drehwage von F. Reich. Freiberg 1838.* This result accords very nearly with that, which was found by Cavendish and Hutton.

† Davy, however, afterwards abandoned his hypothesis. See *Consolation in Travel, or the Last Days of a Philosopher.*

‡ *Loco cit.*

§ *Loco cit.* iii. p. 57 and 94.

|| *L. c.* p. 172. See also Daubeny's *Description of Active and Extinct Volcanos.* Lond. 1826, p. 372, and v. Humboldt's *Reise*, etc. t. i. p. 195.

tion by means of water, were to enter into combination with chlorine. But it would be strange that such an exhalation should not have been remarked sooner. In order to account for the formation of muriatic acid, he mentions the experiments made by him and Thenard, in which they evolved that acid, by introducing aqueous vapour into a mixture of sand and common salt heated to a red heat. In support of his position, he mentions the occurrence of common salt in the lavas, from one of which (that of *Vesuvius* in 1822), Monticelli and Covelli extracted more than 0.09, and in the slags which cover the white hot lava, and which sometimes contain very beautiful crystals of salt. He farther notices the spongy lavas which contain so much iron-glance, and is of opinion that this may also be a consequence of the sublimation of chloride of iron, and its subsequent decomposition, by coming in contact with aqueous vapour and atmospheric air, while at a red heat.* And, lastly, he mentions that chloride of iron, in contact with water, becomes so exceedingly hot, that it is capable, in large quantities, of raising itself to a white heat, and that the chlorides of silicium and aluminium must be able to produce a much more extraordinary degree of heat.

* We may here notice the formation of artificial crystals of oxide of iron in a potter's furnace. Poggendorff's Ann. v. xv. p. 630. Mitscherlich, who gives an account of this, finds an analogy between this formation and similar ones in volcanos. He explains it by supposing that common salt and steam both act together upon silica or siliceous combinations, and form muriatic acid, and that this comes either alone or with a small quantity of water into contact with oxide of iron, or ferriferous combinations. Thus chloride of iron is formed, which is again decomposed by the aqueous vapours, and, if the decomposition proceed slowly, the oxide of iron remains behind in large crystals.

In some volcanic eruptions, the conditions necessary for the formation of iron glance seem, indeed, to have been very frequent, whilst in others they have been entirely wanting. It is not only the lavas of *Vesuvius*, *Aci-reale* in *Sicily*, and the rents in the lava of *Stromboli*, which contain distinct crystals of iron-mica; but it is also found in the greatest abundance in *Auvergne*, (*Volvic*, *Mont d'Or*, *Puy de Dome*, etc. . . .). On the other hand, it has never been found by Nöggerath in the volcanic masses of the *Siebengebirge*, the *Laacher See*, and the *Eifel*; it has only lately been found that some of the slags of the *Roderberg*, an extinct volcano, about two leagues distant from *Bonn*, are scantily covered with iron-glance. See Thomæ der vulkanische

It cannot be denied that there is some justness in these conclusions. But it must be remembered, on the other hand, that the premises are only taken from appearances at *Vesuvius*,* and that the occurrence of common salt and muriatic acid in the products and exhalations of volcanos, seems by no means to be general. We have already quoted Boussingault's observation, that muriatic acid is not evolved from the volcanos under the equator in the New World. The hot springs in those regions contain but little common salt.† In my frequent excursions in the vicinity of the *Laacher See* and in the *Eifel*, I have never found any efflorescence of salt either on the undisturbed or fresh broken lavas, and other products of the extinct craters in those districts. On the uncovered walls of trass, in the *Brohl* valley, efflorescences are, indeed, to be found, but they contain chlorides only as very subordinate ingredients.‡ The lixiviation of trass, basalt, and other volcanic rocks, also gives but a trace of common salt.§ That muriatic acid must have played a very insignificant part in the eruptions of these ancient volcanos, seems to be proved by the mineral springs which rise in their vicinity; for common salt is one of their least considerable components, indeed they frequently contain mere traces of it. This is the result of more than forty analyses of mineral springs in those regions, which I have undertaken during these last few years. But these waters would extract the chlorides from the volcanic masses through which they flow, if they existed in any considerable quantities in them, and would return impregnated with them to the surface.

From all this we do not seem to be justified in considering the chlorides as the chief agents in volcanic phenomena, al-

Roderberg, &c. Bonn, 1835, p. 22. It is worthy of notice, and speaks in favour of the probability of the above-mentioned production of iron-glance, that in the places last mentioned, the appearance of combinations of chlorine is very limited.

* The observations of Von Humboldt, Gay-Lussac, Von Buch, and Monticelli, made at different times, shew also that the exhalations of muriatic acid are very variable. They are sometimes so frequent as to surpass the exhalations of sulphurous acid, sometimes only a few traces of it are found.

† *Loco cit.* p. 181.

‡ Die vulkanischen Mineralquellen, &c. p. 243.

§ *Idem*, p. 246 and 277.

though it cannot be denied that they may, in some instances, co-operate in their production.* It has even been supposed that the beds of rock-salt are of volcanic origin. But this proves nothing more than that rock-salt may have been raised from the interior of the earth by volcanic power, and that the beds of salt are a consequence of volcanic action, but not conversely, that chlorides and the disengagement of muriatic acid are the cause of that phenomenon.

Now, since neither any process of oxidation, nor processes in which chlorides take an active part, are capable of affording a satisfactory explanation of volcanic phenomena, we can scarcely conceive any other powerful chemical process, which could alone give rise to them. We may, therefore, look upon the hypothesis which seeks the cause of volcanic phenomena in intense chemical action as untenable.

* Many volcanos have produced considerable quantities of common salt, as, for instance, *Vesuvius*, *Heda*, &c. Also sal-ammoniac is found among the volcanic sublimations of *Vesuvius* and *Etna*, and almost exclusively in some volcanos of the interior of *Asia*. Vauquelin found in a porous rock, constituting a considerable part of the *Puy de Sarcouy*, in the chain of the *Puy de Dôme*, 0.055 of muriatic acid, which is worthy of remark in connection with the frequent occurrence of iron-glance in that neighbourhood. (*Ann. des Mus.* vi. p. 98.) There are felspar crystals in the trachyte, coloured sulphur-yellow by muriatic acid vapours of a former time. Common salt also forms the chief ingredient in the thermal springs of *St Nectaire*, in the department *Puy de Dome*. In the mineral springs of *Mont d'Or*, *Vichy*, *Chaudes-Aigues*, *Vals*, &c. on the contrary, it is in very small quantities. In the lavas of *Etna* 0.01 of muriatic acid has been found. In basalt, Kennedy found 0.01; Klaproth 0.0001; and I, 0.00085 of muriatic acid. I also found that acid in a steatitic substance in the trachyte-conglomerate of the *Siebengebirge*. See "Die vulcanischen Mineralquellen," p. 277. But this occurrence of muriatic acid, which may, perhaps, be found in many other volcanic productions, is far too inconsiderable for us to ascribe to it any great part in the production of volcanic phenomena. Proust tells us that, according to Garicas Fernandez, the celebrated salt-mines at *Pozu*, near *Burgos*, in *Old Castile*, are situated in the centre of a crater, in which the latter collected various volcanic products. *Journ. de Phys.* vol. lv. p. 457.

CHAP. XXII.—*The hypothesis which supposes the temperature of the earth gradually to increase towards the centre, to a red and white heat, explains in a satisfactory manner (according to the present state of science) volcanic phenomena as well as earthquakes.*

If the heat of the earth continually increases with the depth, the rocks must at a certain depth be in a state of fusion. But since they possess such various degrees of fusibility, the more fusible rocks must be in a liquid state, at depths in which the less fusible ones are still solid. At certain depths there must, consequently, be masses of melted rocks, enclosed in the solid rock, in the same manner as iron ores are melted and reduced in the less fusible masses of which blast furnaces or crucibles are composed. These depths must, according to the above hypothesis, be looked upon as the seat of volcanic action. The crystalline rocks are the most easy of fusion on account of their containing alkalies, which indeed are not wanting in any of them. So that, in general, the more abundantly alkaline minerals, as felspar, mica, leucite, &c., are contained in volcanic masses, the more readily will they fuse.*

Sir James Hall† has endeavoured to ascertain the degree of fusibility of various lavas and other volcanic rocks. Lava from *Vesuvius* of the year 1785, melted at 18° of Wedgewood's pyrometer, lava from *Torre del Greco* not till 40°. But their fusibility varied very considerably, according as the melted lava had been cooled rapidly to a glass, or more slowly to a stony crystalline mass. Thus, for example, those two lavas, when in the form of a glass, both melted at the same degree (18°), whilst the lava of 1785 was less fusible than that of *Torre del Greco*, when of a stony nature.‡ From other appearances it may, in general, be concluded, that the fusibility of lavas is between

* According to Von Buch (Abhandlungen d. Königl. Acad. d. Wissenschaften zu Berlin, 1818-1819, p. 62) it may be taken as a general rule, that all real lavas, which flow in streams down the sides of volcanos, contain glassy felspar. *Vesuvius* being the only exception out of so many is not worth mentioning.

† Transact. of the Roy. Soc. of Edinburgh, vol. v. &c.

‡ Glass is well known to be acted upon in a similar manner. When converted, by being melted and slowly cooled again, into Reaumur's porcelain, it comes less fusible.

that of silver and copper. Thus in the lava of *Torre del Greco*, some gold and a few copper coins were unmelted; but the silver coins were melted and fused with some copper coins.* Davy found that a wire of $\frac{1}{80}$ of an inch in diameter, and a silver-wire of $\frac{1}{10}$ of an inch in diameter, thrust into the lava near its source, instantly melted. A rod of copper $\frac{1}{8}$ of an inch in diameter, which I held in fused basalt, flowing out from a furnace, melted. But the basalt was doubtless heated far above its melting point. Now according to Daniel,† silver melts at 2293° F. at 2548° F.; we may therefore take a mean temperature ($=1000^{\circ}$ R.) for the melting point of lava.

Now, if we suppose the increase of temperature to continue to follow the same progression as has been observed at accessible depths, the lava must be in a state of fusion at the observations near *Geneva* and in *Lucerne* at a depth of about 113505 feet, and from those in *Italy* at about 126829 feet below the level of the sea, or *Etna*.§

If we suppose steam to be the power by which the lava is raised from this enormous depth, and by which the bombs, rapilli, and ashes are thrown up, and according to observations hitherto made, water in its elastic state may be the only means by which the lavas|| and other

* Thompson: Notices of an English Traveller, &c. Breislach's *Italy*, la Camp., vol. i. p. 279) mentions, that when bell-metal was placed in lava, the zinc melted out, leaving the copper behind.

† Annal. de Chim. et de Phys. vol. xxxviii. p. 138.

‡ Journ. of Science, xxiii.

§ According to my observations made on a cooling basalt-bath of seven inches diameter, and which I shall communicate afterwards, the increase of temperature from the surface towards the centre of the bath takes place, not in an arithmetical, but in a geometrical progression, the exponent of this progression being but very little greater than 1, the progression comes very near to an arithmetical one. The depths, above mentioned, being but insignificant in proportion to the diameter of the globe, the error has been committed in supposing the increase of temperature to be an arithmetical progression as far as these depths. With this exception, we can hardly hope ever to become acquainted with the true nature of the increase of the temperature to the interior. Therefore, as the former, can but give approximations to the true

|| Von Humboldt's Reise, t. i, p. 186. A short time after the eruption of *Vesuvius*, in the year 1805, he and Gay-Lussac

rocks,* are so raised; it is yet a question whether its expansive force could be sufficiently raised by heat? Parrot† reckons that the temperature of lava, at the moment of its ejection, is five times as great as would be necessary to raise it 48000 feet by the elastic force of steam, supposing the steam to be formed in the presence of water. But from more recent inquiries on the elastic force of aqueous vapour, this calculation must undergo considerable corrections. The formula of Mayer, as altered according to the last results of the experiments at Vienna‡ corresponds the most nearly with the elastic force of steam as actually observed, so that it may be considered as the most correct determination of its elasticity at higher temperatures. If we wish to find the pressure of the steam in Paris inches of a column of mercury from this formula, we shall have

$$\log e = 2.8316686 + \log (213 + t) - \frac{847.3}{140 + t}$$

in which t is the temperature in degrees of Reaumur = $\frac{4}{9}$ F. §

tery vapours in the interior of the crater did not redden litmus. Many other naturalists have also found that the outlets of smoke of the *Peak of Teneriffe* emitted pure water only. Voy. de La Peyrouse, t. iii, p. 2. Hoffmann, in his letter to Von Buch on the geognostical structure of the *Lipari Islands*, in Poggendorff's *Annal.* vol. xxvi, p. 9 and 45, and in several places in his account of the volcanic island which rose in the *Mediterranean Sea*, vol. xxiv, p. 65. According to Monticelli and Covelli, the smoke which rises from the lava-streams consist almost exclusively of aqueous vapour. *Loco cit.* p. 27, 65, and 83. Numerous fumaroles (exhalations of aqueous vapour) rise on the island of *Ischia* out of the cracks in the lava. Forbes in *Edinb. Journ. of Science*, N. S. iv, p. 326. Reinwardt, *Verhandlingen van het Bataviaasch genootschap van Kunsten en Wetenschappen*, negende deel, Batavia 1823, p. 1. Ordinaire mentions, in his "*Histoire Naturelle des Volcans*," a mass of melting iron having been cast to a height of 150 feet, out of a blast furnace, by some water having accidentally got into it. See D'Aubuisson, *Traité de Geognosie*, v. i, p. 215.

* The water contained in basalt speaks in favour of this opinion. See Klaproth's *Beiträge*, &c., vol. iii, p. 249, and Kennedy in Appendix to the same, p. 255. On melting basalt, and introducing a gun-barrel into the crucible, I observed a considerable evolution of aqueous vapour.

† *Grundriss der Physik der Erde und Geologie.* Riga u. Leipzig, 1815, p. 264.

‡ Arzberger in the *Jahrbüchern des Polytechnischen Instituts*, vol. i p. 144.

§ On steam and steam-engines in the *Abhandlungen der Königl. technischen Deputation für Gewerbe*, part i, p. 344.

It is clear that the elastic force of steam cannot surpass a certain maximum, which it reaches when its density is equal to that of water. This is the case when the elasticity of the vapour $e = 232952$ Paris inches of mercury, or nearly 8320 atmospheres, which supposes a temperature of 2786° F.*

Thus, if aqueous vapour were to reach its greatest possible elasticity, its temperature must exceed that above assumed for the melting point of lava by 504° F. The highest column of lava, which steam at its maximum elasticity is capable of supporting, is, therefore, if we suppose the specific gravity of liquid lava three times as great as that of water, 88747 feet. But a temperature of 2786° F. will, according to the observations at *Geneva* and in *Cornwall*, be met with at a depth of 139265 feet, and according to those in the *Erzgebirge*, at a depth of 155613 feet (about thirty English miles) below the level of the sea near *Vesuvius* or *Etna*.†

Supposing, then, the values found for the maximum elasticity of steam for the corresponding temperature, and for the depth at which that temperature must exist, to be correct, it would not be possible, that a column of lava, of the whole height, from the seat of the volcanos to the surface of the earth, should be raised up. On the other hand, in the same manner as a bubble of air let into a barometer, drives the mercury into the Torricellian vacuum far above the barometric height, aqueous vapour may raise a column of lava of a height equal to its expansive force into the channels opening into the craters. Thus, then, it may happen that aqueous vapour, though far from its maximum elasticity, may yet be able to raise a column of lava equal in height to its elasticity from still greater depths to the surface of the earth. A continual alternation of columns of lava and steam in the channels may be very well conceived, the consequence of which would be an alternate ejection of lavas, red hot masses,

* On steam and steam-engines in the *Abhandlungen der Konigl. technischen Deputation für Gewerbe*, part i. 344.

† Supposing the mean temperature of this locality = 61° F.

and clouds of steam, just as Spallanzani,* Scrope,† and Hoffmann,‡ observed on *Stromboli*.

We have now to examine the circumstances under which water might find its way to the origin of volcanic action. The difficulties which present themselves when we suppose a direct communication between the sea and the seat of the volcanos, have already been discussed by Gay-Lussac. We shall make an attempt to solve these difficulties.

If we imagine the sea to have free access by means of fissures to the seat of the volcanos, the depth of which, according to the above calculation, may be taken at from 113505 to 126829 feet, the elastic force of steam at that depth, where $t = 2282^{\circ}$ F., will be = 5310 atmospheres. But the hydrostatic pressure of these columns of water is only from 3547 to 3963 atmospheres. The expansive force of steam at that depth in which the temperature is 2282° F. is, therefore, greater than the hydrostatic pressure opposed to it, so that the latter cannot resist it. But since, as the temperature decreases, this expansive power diminishes more rapidly than the hydrostatic pressure, there must be a certain depth and a corresponding temperature in which they will be in equilibrium. For a constant increase of temperature of 1° F. in 51 ft., this point will be at the depth of 88044 ft. below the surface of the sea, where

* Voyag. t. ii. p. 21.

† Considerations on Volcanos, &c. p. 54. A phenomenon observed by Scrope during the night in the crater of *Stromboli* distinctly shows, that, by the force of aqueous vapours alone, the column of lava is raised. The lava once suddenly disappeared in the depth of the crater; on the contrary, innumerable little columns of steam appeared at the edges of the mouth of the crater, which arose with a hissing noise. This lasted for some minutes, when the melted mass rose again from beneath, and the phenomenon pursued again its ordinary course. Spallanzani remarks very justly with a view to this, that the compressed vapours prevented from being discharged by the sinking lava which had become tenacious on the surface, will now escape laterally through the fissures in the walls of the edge of the crater, and in this case the lava cannot be elevated by them. It is not until the lava has been sufficiently heated and become again liquid, that the vapour can rise again with the lava, and that the phenomenon can be re-established.

‡ Loco cit. p. 9.—D. Curbeto also observed that a dense smoke always followed the streams of lava which were ejected on the 7th June 1731, Von Buch in the Abhandl. d. Berliner Acad. of 1818–1819, p. 77.

the temperature is $1754^{\circ}.5$ F.;* for, according to the above formula, if t be taken equal to $1754^{\circ}.5$, $e = 77028$ inches of a column of mercury, or $\frac{77028}{28} = 2751$ atmospheres, and $\frac{88044}{32}$ gives the same number. On the other hand, for a constant increase of temperature of 1° F. in 57.1 ft. it advances to a depth of 105627 ft. below the surface of the sea, where the corresponding temperature would be $1881^{\circ}.5$ F.;* for the same formula gives $e = 92435$ inches of a column of mercury, or 3301 atmospheres, when $t = 1881^{\circ}.5$, and $\frac{105627}{32}$ gives the same value. Presupposing the correctness of the premises, these calculations shew the possibility of columns of lava of $\frac{88044}{3} = 29348$ and $\frac{105627}{3} = 35209$ ft. being raised by the power of steam from the respective depths of 88044 and 105627 ft. below the surface of the sea, whilst there is an uninterrupted communication between the sea and the volcanic focus. The difficulty mentioned by Gay-Lussac, that the water would, under its own pressure, take the gaseous form before reaching the strata, which are at a white heat; without being able to raise the lavas, to cause earthquakes, and to support the volcanic phenomena; is consequently also set aside, in so far that the water cannot assume the form of gas under its own pressure before reaching those depths and their corresponding temperatures. At depths greater than 88044 or 105627 ft. below the surface of the sea, if the communication with the sea remained free, a reaction would take place in the column of water. Perhaps the phenomena mentioned in chap. xi, on Hot and Mineral Springs, and observed by Horner near the *Kurile Islands*, as well as the powerful stream of hot steam, observed by Hoffmann near *Vulcano*,† beneath the surface of the sea, probably at the same place where the crater of the cone formerly thrown up at this spot was situated, proceeds from a similar volcanic effervescence. In general the rising of smoke from the sea during the eruptions of neighbouring volcanos is by no means an uncommon occurrence.‡ The reflux and the

* To simplify the calculation, I have supposed the mean temperature of the surface = 32° F.

† Loco cit. p. 67.

‡ D. Curbeto (Von Buch loco cit. p. 78) observed a great quantity of smoke

internal agitation of the sea is also a forerunner of almost all eruptions, especially of those of *Vesuvius*.

But if a reaction should take place in the column of water, yet the rising vapour would soon be so far cooled down as to become liquid again, without the expansive force of the enormous quantities of vapour formed at the volcanic focus being thereby perceptibly diminished. In addition to this, the hydraulic resistance in the narrow channels, through which the water is admitted, increases very considerably as its velocity becomes greater. But the column of water, by which the aqueous vapour is cut off from communication with the surface, acquires very great velocity in those narrow channels, from the enormously increased elastic force of the steam, by which the resistance may very easily be increased to the extent of much more than 1000 atmospheres. So that, notwithstanding that the expansive force of steam whose temperature exceeds 1754° or 1881° F. is greater than the hydrostatic pressure of the column of confining water, yet this resistance may suffice, in the manner just mentioned, to raise a column of lava, of even a greater height than we have above reckoned, to the summit of the volcano. If we may be allowed to make a comparison with an analogous phenomenon, it may be remembered that the touchhole of a cannon, or of a bore-hole in a mine, does not weaken much the action of the powder, although the proportion of the diameter of the touchhole to that of the mouth of the cannon is as 1 : 30.* If Perkins's well known observation, †

and flames (?) accompanied with tremendous detonations, rise from the sea near *Lancarote*, during the volcanic eruption on that island. Fish and pieces of pumice were seen floating about. Several examples of this sort are cited farther on.

* But even when the touchhole becomes considerably widened by frequent use, the cannon is still of service, although, indeed, its power is somewhat diminished. Yet the force with which the powder projects the ball is equal to about 2200 atmospheres, in which the loss occasioned in the absolute expansive force of the powder by the touchhole, &c. is already allowed for. Muncke in *Gehlers Physikal. Wörterbuch*, new edition, v. 1. p. 712.

† *Quarterly Journ. of Sc.* July to Dec. 1827, p. 471, and *Annal. de Chim. et de Phys.* xxxvi, p. 435. See also Muncke in *Poggendorff's Ann.* vol. xiii, p. 244, and Buff in the same, vol. xxv, p. 591.

fissures in the rocks,* by which the waters are admitted in other places. But in doing so, it may frequently happen that these fissures do not communicate with the channels by which the water is admitted, and that the volcanic action is consequently for a time suspended, but that on its revival the slightest shock is sufficient to break through the walls, and thus to reopen the communication.† This may even be caused by the expansion of the cooled walls of the focus by the heat communicated to them from all sides; in the same manner as a small crack in a crucible increases when exposed to a red heat.

The more the temperature of the lava is reduced by the water and the generation of the steam, the longer will be the time required for the refusion of the solidified lava. In this manner a long period may elapse, as the lava is so very bad a conductor of heat.‡ The repose and activity of a volcano are, therefore, the alternate solidification and liquefaction of the lava, and the interruption and renewal of the supply of water to the volcanic focus.¶ If the store of lava in the volcanic focus should at first become exhausted by repeated discharges, the volcano is entirely reduced to a state of rest, or at least until it receives a

portion as the elasticity of the vapours diminish, the substances will be thrown to a less distance, so that the black rapilli, which are the first ejected after the lava has ceased to flow, will be cast farther than the white ones. Von Humboldt's *Reise*, t. i. p. 245.

* It is well known that considerable fissures are formed in lava during its cooling, especially when it is on the surface of the earth. The streams of lava in the country surrounding the *Laacher-See*, offer many instances of this kind. Hamilton also mentions great fissures in the lava-streams of *Vesuvius*. Gilbert's *Annal.* t. vi. p. 23. See also Necker, *loco cit.*

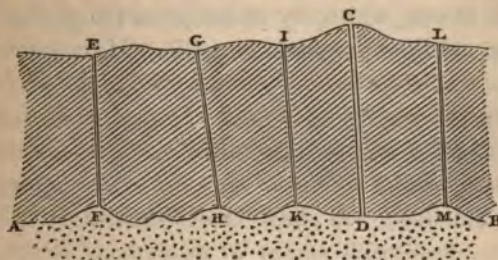
† We may here notice the well-known phenomenon, that among the ejected masses from a volcano, pieces of rock occur, which neither belong to the substances composing the edge of the volcanic cone, nor to those found in the vicinity, and therefore must be derived from masses concealed very deep under the volcano. *Vesuvius* particularly, furnishes remarkable instances of this kind. Such ejected masses, however, are now found much more rarely than formerly on this or other volcanos, from which it seems to follow, that the channels of the ejections have been by degrees widened.

‡ Monticelli and Covelli, *loco cit.* p. 15 and 39.

¶ Experiments hitherto made shew, that long spaces of time are requisite to produce the strongest effects, viz. the elevation of lava to the greatest height. Von Humboldt (*Reise*, &c. t. i. p. 261.) calls our attention to the circumstance, that long intervals of quiescence seem to characterize the

fresh supply of lava from a distance. If the afflux of water be not interrupted, the exhalations of vapour may still continue, of which we have already mentioned several instances.

We may next consider how lava may be elevated from the depth of a volcanic focus. The hypothesis, which ascribes volcanic phenomena to the central heat, supposes that melted matters exist at a certain depth. In adopting this opinion, we need not assume that lava is produced by the melting of solid rocks, but on the contrary, that melted matters have existed since the creation of the world.† In the annexed diagram



very high volcanos. The smallest of all, *Stromboli*, is nearly always in activity. The eruptions of *Vesuvius* are less frequent, although they are still more so than those of *Etna* and the *Peak of Teneriffe*. During the quiescence of the latter, from 1706 to 1798, sixteen eruptions of the former took place. From the colossal summits of the *Andes*, *Cotopaxi* and *Tungurahua*, an eruption is observed scarcely once in a century. We may venture to state, that the frequency of the eruptions of active volcanos is inversely as their height and mass. After these general remarks, we may mention the circumstance that large lava streams, namely, such as issue from *Etna* and *Vesuvius*, never flow from the crater itself, and that the quantity of the melted matters is commonly inversely as the height of the fissures from which the lava issues. But a lateral eruption of these two last-mentioned volcanos always terminates by an emission of the ashes from the crater, that is, from the summit of the mountain itself. This phenomenon has not been seen on the *Peak of Teneriffe* these last hundred years. The crater was most inactive during the eruption in the year 1798. Its basis did not sink, whilst the greater or less depth of the crater of *Vesuvius*, according to the acute remark of Von Buch, is an almost infallible sign of an impending fresh eruption. Von Humboldt, p. 268. All this shews that the conditions requisite for producing the greatest effect, viz. for producing the highest degree of the increased elasticity of the watery vapours, are not always present.

† On this supposition, we assume that no basalt has been produced by the repeated melting of any known rock. Leonhard's Basalt Gebilde &c. Stuttgart, 1832, t. i. p. 263.

AB represents the boundary between the solid crust of the earth and the melted matters in the interior of the earth; CD represents a wide rent, exhibiting a communication from the surface to the melted matters; EF, GH, IK, LM, &c. are narrow rents conducting water from the sea or subterranean collection of water to the heated interior;* and F, H, K, M may be caverns in the solid crust, formed during the consolidation of the originally fluid matters of a former period. Under these circumstances it may easily be conceived, that water penetrating into the above-mentioned rents and caverns is converted into steam, which, by pressing on the melted matters, causes them to rise through the rent CD. If the lower opening in the wide rent at D be on the same level as the whole boundary between the solid rocks and the melted matters, small quantities of these only will be raised upwards, for the surface of the melted matters will soon sink below the opening of the rent at D, and steam will rise. Thus the elevation of a column of lava to a considerable height by a column of steam will take place. But if the lower opening of the rent CD descends more or less below the surface of the melted matters, considerable quantities of these will rise into it before this surface sinks below the opening. The same may take place if, between the opening of the rent CD and the other rents (those down which water flows from the surface), ridges of solid rock reach downwards from the solid crust into the fluid mass.

Such ridges may be viewed as occasioned by gradual solidification of the fluid mass from above downwards, for it is well known that melted matters, if they crystallize by cooling, exhibit on their under surface considerable inequalities; and the consolidation of the melted matters in the interior of the earth is assuredly produced by crystallization.

There is another circumstance which may cause a continuation of the rent CD into the melted matters. After the rising of the lava and steam in this rent, the walls of it are cooled by the formation of steam, and by the atmospheric air having a ready access to the empty channel. Therefore these walls

* Water will naturally also penetrate into the wide rent, but, inasmuch as it is not able to fill up the rent, it cannot confine the steam generated beneath, and the latter will therefore escape.

may gradually increase by the solidifying of the melted matters; nay, the rent may be entirely solidified and obstructed, so that it can only now be re-opened by the force of steam previous to a new eruption taking place. If even immense quantities of lava are ejected by the steam, yet the level of the melted matters in the interior may be but slightly changed, for in the same manner, as all seas on the surface of the earth communicate together, so the melted matter in the interior does the same. However, more or less time may elapse, before the melted matter which has sunk at one place in consequence of ejection, can regain its former level by the afflux of other melted matters from a distance. Therefore the repose and activity of a volcano, besides depending on the interruption and renewal of the supply of water to the volcanic focus, may also proceed from the alternate obstruction and re-opening of the lava channel by the melted matters. In the latter case, in the state of rest, exhalations of steam will take place, inasmuch as water penetrates continually to the volcanic focus.

But if the afflux of water be interrupted by an obstruction of the water-ducts, and if none of the above-mentioned causes be capable of restoring the communication; or if, during the repose of the volcano, the lava-ducts become so obstructed by consolidation, that the steam cannot force its way through them, a volcano may reach a state of perpetual repose. Such causes may have effected the extinction of the volcanic activity of the numerous extinct volcanos distributed throughout the globe. If this took place at a former period, when the thickness of the crust of the earth was still increasing considerably, in consequence of the gradually cooling of the earth, and as this process is still going on, there is no probability that such extinct volcanos will at any time become again active.

If volcanos, for instance *Etna*, are considerably elevated above the surface of the earth, it commonly happens that the walls of the lava-channels cannot resist the pressure of the melted matter in their interior. In this case rents are formed from which the lava issues. Such rents are always seen in the direction of the axis of the volcanic cone,* and their extent is

* Von Buch's Beobachtungen, &c. t. ii. p. 137.

often very considerable. A rent of this description produced by one of the most violent eruptions of *Etna*, viz. that of the 11th May 1669, was $2\frac{1}{2}$ German miles in length, and occupied almost one-third of its height. Scrope* saw distinct traces of it near *Nicolosi* so late as the year 1819. Even the rent formed during the eruption in 1794 on the declivity of *Vesuvius*, towards *Torre del Greco*, was, according to Von Buch, 3000 feet in length, and according to Breislak 237 feet in breadth at its upper edge.

Other volcanos afford instances of the formation of rents and hills. Thus during the most violent eruption of *Scaptar Jokul* on *Iceland* in 1783, a rent eight English miles in length was formed in a plain at the foot of the mountain. Three craters, from which immense quantities of lava flowed out, rose in the direction of the rent, and afterwards a fourth appeared below the sea in the same direction, and at a distance of thirty miles, the eruption of which formed an island, which afterwards disappeared again.† Similar phenomena took place in the same year in the island of *Java*. And Von Buch‡ informs us, that in the island of *Lancerote*, during the eruption in the year 1730, a rent was formed above two German miles in length, on which about twelve conical hills rose, whose summits were from 600 to 800 feet in height.

In like manner basaltic cones, (also porphyritic and granitic hills) are often seen, which are situated in a line, and of which two or more are connected by rents, which are filled up by basalt. Remarkable phenomena of this kind are seen near *Murol* in *Auvergne*.§

It seems surprising that the same kinds of lava are not always ejected from volcanos. Von Buch || distinguished on *Vesuvius* alone eighteen distinct principal kinds of lava; and old and new lavas of *Etna* also differ in their characters. The lavas of neighbouring volcanos are often very different from each other. In like manner, unstratified rocks of very different natures are

* Considerations, p. 158.

† Ibid, p. 154.

‡ Leonhard's Taschenbuch, 1824, t. ii. p. 439.

§ Leonhard's Basalt Gebilde, t. i. p. 408.

|| Beobachtungen, &c. t. ii. p. 174.

often met with close to each other.* The *Siebengebirge*, near *Bonn*, offer remarkable instances of this kind. There, trachytes, trachyte tuffs, basalts, and basalt tuffs, are met with close to each other. Basalt dykes traverse the trachyte and the trachyte tuffs, and volcanic scoriæ occur on the *Roderberg*, opposite to the *Siebengebirge*, on the left bank of the *Rhine*. However different all these rocks are, yet they seem to lead to the conclusion that their origin has been from the very same materials; for, notwithstanding this difference in their nature, it would be easy to form in the *Siebengebirge* a gradation from a white trachyte to a compact black basalt.† On the other hand, there is every reason to suppose that the nature of the melted matters in the interior is different in different places. If, therefore, after the ejections of melted matters existing in a particular spot, new eruptions will take place only when such matters flow from remote places towards this spot, we can hence easily conceive how different lavas may be ejected at different times. In the *Siebengebirge*, as well as in other places where unstratified or volcanic rocks occur, many instances are exhibited, which indicate that these rocks are of very different ages.‡

If the activity of a volcano ceases, but the channels by which the waters enter remain open, the volcanic action may be replaced by hot springs.§ In this case it is easy to conceive that the meteoric waters, continually sinking into the hot interior, would there assume the surrounding high temperature, and rise again to the surface with a temperature, diminished proportionally to the decrease of pressure, either through the former

* The lavas of *Vesuvius*, of the *Solfatara*, of *Ischia*, and of *Etna*, are quite different in their nature.

† See Leonard Horner on the Geology of the Environs of *Bonn*, in the Transactions of the Geological Society, vol. iv., 2d Ser. p. 433. Von Buch states that in several places in the neighbourhood of *Clermont* and *Puy de Dome*, a transition from granite into trachyte may be traced, and thus to have the gradation extended from granite to basalt.

‡ L. Horner, l. c. p. 467.

§ Von Buch, loco cit. p. 65. A remark of some interest in tracing the connection of hot springs with volcanic phenomena is made by Burkart, loco cit. vol. i. p. 316, viz. that the boiling hot springs in the valley of *Pate* are situated on a line, running from east to west, parallel to the general line of volcanos in *Mexico*.

lava-channels, or other fissures more recently opened.* But if at that depth, the hydrostatic pressure be greater than the elastic force, which the water has there acquired, no steam will be generated in the whole course of the spring; but, in the contrary case, from the lowest point up to the point where the elastic force becomes greater than the hydrostatic pressure, the water will escape in the form of a vapour. However high the temperature of the water may be at the lowest point of its course, whether in the liquid or in the gaseous state, yet, when it reaches the surface, it cannot exceed the boiling point. The reason of springs but seldom attaining even this maximum may be either the loss of heat communicated to the superior strata of the earth, or that they meet with streams of gas, (carbonic acid, or sulphureted hydrogen), which, even if possessed of a very high temperature, will cause a depression of their temperature, as is proved by experiments cited in Chap. II. p. 8. The production of hot springs, according to the last species of volcanic action, may, however, be thus imagined; that the water which descends to the volcanic focus is there converted into steam, which, rising through fissures into higher regions, meets with atmospheric waters which it warms, and with them returns to the surface.† The course of hot springs produced in this manner can, therefore, occur only at inconsiderable depths below the surface. Lastly, it may happen that the lava last raised did not escape from the crater or its lateral openings, but became solid on its

* Von Humboldt is also of opinion, *Reise*, &c. t. i. p. 187 and 188, that the vapour which rises from the "*Narices del Pico*" as they are called, and from the rents in the crater of *Teneriffe*, is nothing but atmospherical water which has penetrated by infiltration.

† According to M. Arago, the hottest spring in *Europe* unconnected with modern volcanic action is that of *Chaudesaigues* in *Auvergne*, whose temperature he quotes at 176° Fahr. *Annuaire du Bureau des Longitudes*, 1836. The next hottest to this seems to be *Thuez*, in the *Pyrenees*, whose temperature is, according to Professor Forbes, 171.°5 Fahr. *Phil. Trans.* t. ii. p. 603, for 1826. Forbes believes, p. 610, the baths of *Nero*, near *Naples*, the hottest spring on the Continent of *Europe*, which is connected with modern volcanic action, the temperature being 182.°2 Fahr.

‡ Perhaps the numerous hot mineral springs which rise at the foot of the still smoking mass of rocks on *Pantellaria*, as well as the numerous hot sulphureous springs in the vicinity of *Sciacca*, in *Sicily*, have a similar origin. Hoffman, l. c.

way onwards, and thus stopped up the channels. If, in this case, water should descend through rents into this still extremely hot lava, hot springs would also thus be produced, supposing a communication between these and other rents which lead to the surface at a lower level; but these springs will decrease in temperature by degrees as the lava gradually cools, till they reach that degree which naturally belongs to the place where the lava is situated. However, we have already proved by experiments formerly mentioned, and calculations founded upon them, that, if such masses of heated lava be of considerable extent, a very long period may elapse before the decrease in the temperature of the springs will be even perceptible.* On the other hand, there are examples of a very rapid decrease in the temperature of hot springs in the neighbourhood of volcanos recently become extinct. Thus, the temperature of the hot springs on *Jorullo* decreased $40^{\circ}5$ F. in 24 years, between the visits of Von Humboldt and Burkart.† The temperature of the mixture of gases which issues from the rents in the Pass of *Quindiu*, near the *Moral*, in the *Quebrada del Azufreal*, decreased from 1801 to 1827, according to the observations of Von Humboldt and Boussingault, from 118° to $66^{\circ}4$.‡ If, instead of this gas, a mineral spring had flowed at this place, it would, doubtless, have suffered a similar diminution of temperature. Boussingault mentions, on the other hand, that, in a period of twenty-three years, the temperature of the hot springs of *Mariana* and *Las Trincheras* rose several degrees. According to the observations of Hamilton, Della Torre, Abbé Soulavie, Von Humboldt, and Forbes, the hot spring named *La Pisciarella*, which rises near *Naples*, from the exterior of the cone of the *Solfatara*, is subject to extraordinary alternations in its temperature, from 101° F. to $199^{\circ}4$ F.§ But even in very short periods striking differences are some-

* Die vulkanischen Mineralquellen, &c. p. 150.—I have calculated, that, under the circumstances there mentioned, a mass of melting basalt, equal in size to one-third of the *Donnersberg*, near *Milleschau*, in *Bohemia*, would be sufficient to have heated all the water which has issued from the whole number of springs at *Carlsbad* since the time of Adam.

† Burkart, loco cit. t. i. p. 226.

‡ Poggendorff's Annal. t. xviii. p. 353.

§ Forbes, loco cit. p. 611.

times found. Thus Forster* asserts, that in the neighbourhood of *Tanna*, a volcano on one of the *New Hebrides*, the hot springs vary several degrees in temperature from one day to the other.

There is not, perhaps, a more striking example of the intimate connexion existing between volcanic phenomena and hot springs than in Iceland. As the volcanic eruptions are there confined to the district of the trachyte-formation, so also are the principal mineral springs only found in this formation;† from which it seems natural to infer, that it is one and the same process acting in both cases, but in a different manner.‡

The hot springs in this volcanic island confirm Krug Von Nidda's system of classing thermal springs—namely, 1. *such as are constantly bubbling and boiling up—permanent thermals*; 2. *those in which this ebullition only takes place at particular periods, and which are perfectly tranquil during the remaining time—intermitting thermals*; and, 3. *those whose surface is always undisturbed, and in which no bubbling or boiling ever takes place*. The springs of the first class always have a temperature at the surface equal to that of boiling water under the usual atmospheric pressure. Those of the second class only reach the boiling point during their temporary ebullition, and lose considerably in temperature during their period of rest. The springs of the third class never reach the boiling point of water.

The most famous of the intermittent springs is the *Great Geyser*. At the time when Krug Von Nidda visited it, it presented two different kinds of eruption. The smaller ones were repeated regularly every two hours; and the water was thrown only from fifteen to twenty feet high. The greater ones succeeded each other at intervals of from twenty-four to thirty hours; in these cases, the masses of steam ascended to the clouds, and the water spouted to a height of ninety feet. For two hours after one of the smaller eruptions, during which time there were no traces of action, and only thin clouds of

* Journ. de Phys. 1779, p. 434.

† All the hot springs of *Mexico* also rise out of trachyte and dolerite rocks. Burkart, p. 363.

‡ Krug Von Nidda on the mineral springs of *Iceland*, p. 272, in Karsten's Archiv. t. ix. p. 247, and in Jameson's Phil. Journal, vol. xxii. p. 90 and 220.

steam were formed at the surface, the temperature of the water was 194° F., which was reduced still lower by the evaporation. After a dull rumbling noise within, the water suddenly began to boil up again, the basin was filled till it flowed over, immense bubbles of steam burst from the funnel-shaped opening, and projected the water to a height of about twenty feet. Immediately after the eruption, when tranquillity was completely restored, the water was at the boiling point, but its temperature soon fell below that degree.

The *Strokr*, the eruptions of which almost exceed in grandeur those of the *Great Geyser*, has this peculiarity, that it is at the same time a permanent and an intermittent thermal spring. It shews itself to be permanent by its incessant ebullition, and intermittent by the tremendous eruptions which seem to be repeated at intervals of from two to three days.

No doubt can be entertained respecting the nature of the agent by which the waters of the *Geyser*, the *Strokr*, and other less considerable springs, are thrown to such an immense height. It is, as in volcanos, a gaseous body, principally aqueous vapour. We may, therefore, very fairly agree with Krug Von Nidda, and consider volcanos in the same light as intermittent springs, with this difference only, that instead of water they throw out melted matters.

He takes it for granted that these hot springs derive their temperature from aqueous vapours rising from below. When these vapours are able to rise freely in a continued column, the water at the different depths must have a constant temperature, equal to that at which water would boil under the pressure existing at the respective depths. Hence the constant ebullition of the permanent springs, and their boiling heat. If, on the other hand, the vapours be prevented, by the complicated windings of its channels, from rising to the surface; if, for example, they be arrested in caverns, the temperature in the upper layers of water must necessarily sink, because a large quantity of it is lost by evaporation at the surface, which cannot be replaced from below. And any circulation of the layers of water at different temperatures, by reason of their unequal specific gravities, seems to be very much interrupted by the narrowness and sinuosity of the passage. The intermitting springs

of *Iceland* are probably caused by the existence of caverns, in which the vapour is retained by the pressure of the column of water in the channel which leads to the surface. Here this vapour collects, and presses the water in the cavern downwards until its elastic force becomes sufficiently great to effect a passage through the column of water which confines it. The violent escape of the vapour causes the thunder-like subterranean sound, and the trembling of the earth, which precede each eruption. The vapours do not appear at the surface till they have heated the water to their own temperature. When so much vapour has escaped that the expansive force of that which remains has become less than the pressure of the confining column of water, tranquillity is restored, and this lasts until such a quantity of vapour is again collected as to produce a fresh eruption. The spouting of the spring is, therefore, repeated at intervals, depending upon the capacity of the cavern, the height of the column of water, and the heat generated below.*

The two distinct classes of eruption in the *Geyser*, which we have already mentioned, seem to be attributable to two different cavities. A smaller cavity fills quicker, and, therefore, empties itself more frequently; a larger one fills slower, empties itself seldomer, but with greater violence. But the playing of the *Geyser*, the *Strokr*, and some others, is subject to very great

* The eruptions of the *Geyser* and the *Strokr*, as observed by Krug Von Nidda, agree exactly with his explanation of the action of the intermitting springs of *Iceland*. A thick column of smoke suddenly burst out of the latter, and rose to the clouds. The water was hurled with terrific violence out of the crater, and mixed like a fine mist with the rest of the column to a considerable height. From time to time thin streams of water were seen shooting in a vertical or oblique direction through the column of smoke, sometimes rising to a height of a hundred feet and upwards. Large stones, which had been previously thrown in, were flung almost out of sight, and many so perfectly vertically that they fell down again into the crater, and were again thrown up into the air, like a juggler's ball. The whole of the water was thrown out at the beginning; and afterwards, the column which ascended from the opening, was composed only of steam, which rushed out with a whistling and hissing noise, and rose with incredible velocity into the clouds. It continued for three quarters of an hour in this state of activity. It then again became quiescent, except that the water, deep in the tube, continued, as usual, to boil violently.

variations. Channels may become stopped by the incrusting property of the water. During the frequent shocks which accompany the greater eruptions, some cavities may fall in, and be choked up, and new ones formed. The greatest changes, however, are caused by the earthquakes, which from time to time visit the island. Thus, during the earthquake of 1789, the most important spring in the country, next to the *Geyser*, disappeared, and at present only steam is evolved from its mouth, while the *Strokr*, which before this was but an inconsiderable spring, increased to such an extent, that it is now considered to rival the *Geyser* in importance. It may be observed, that the eruptions of the *Strokr* have no connection whatever with those of the *Great Geyser*. During the long eruption of the former the latter remained quite quiet, and *vice versa*. In general, each of these numerous hot springs, which are here crowded together in a very small compass, seems to be totally independent of each other. This might also be inferred from the striking difference in their levels.

It seems probable from the situation of the celebrated hot-springs of *Iceland* (of which more than fifty may be counted in a space of a few acres, at the foot of a rock about 300 feet high, which leans against a chain of higher rocks); from the numerous fissures in these rocks, which are composed of alternate layers of tuffas, of slag-streams, and slag-conglomerates, as well as from the fact, that the springs are confined exclusively to the lower region, which extends along the foot of the hill, whilst on its sides and summit are found only gaseous exhalations (aqueous vapour and sulphureted hydrogen gas); that these springs are supplied from the meteoric waters of the neighbouring hills, and that, being originally cold, they are indebted for their high temperature solely to the hot vapours which they receive from below. The hot-springs in *Iceland* seem, therefore, to be produced in the manner described at page 50.

Lastly, If the permanent obstruction of the lava and the water channels has taken place, of course no hot-springs can exist, or at least they can only flow during the cooling of the lava last ejected and solidified. This seems to have been the case in the volcanic district of the *Siebengebirge*, the *Laacher See*, and the *Eifel*, as in these places no hot-springs, with the exception of

the baths of *Bertrich*, are to be met with ; although in the two latter districts, the number of thermal springs, whose temperature exceeds that of the soil at the most by a few degrees, are enormous, and considerable exhalations of carbonic gas give evidence of former volcanic action. It may, however, be conjectured, with some probability, that in the vicinity of the *Laacher See* and in the *Eifel*, springs may have existed, whose duration depended on the cooling of the masses of lava. Similar circumstances seem to have occurred in *Auvergne* and *Vivarais*, although the hot-springs, which are not uncommon in those countries, show that many of the former volcanic channels are still unobstructed

The examination of deposits obviously formed from springs, which existed at a former time, may often present an indication of their temperature. Thus, on the volcanic tongue of land called the *Sneefield-Syssel*, in *Iceland*, we find none of the hot mineral springs which are so numerous in other parts of the island, and which are distinguished by their holding silica in solution, and exhaling sulphureted hydrogen gas. But, in former times they existed here, for in many places we find siliceous incrustations in the form of tuffas and sinters. One cold spring, which is now flowing, has certainly taken the place of a hot siliceous spring, for its present deposits are only calcareous, and quite distinct from the older incrustations.* The circumstance that arragonite is deposited from hot-springs, calcareous spar, on the other hand, from cold ones, gives us also an indication of this kind. Since G. Rose† pointed out that the former is only deposited from a hot solution of carbonate of lime, the occurrence of arragonite in any deposit leads us to infer with certainty that these deposits owe their origin to a hot spring. If, on the contrary, we find calcareous spar in any deposit, we may infer with equal certainty that it was produced by a cold spring.‡

* K. v. Nidda, loco cit. p. 282.

† Poggendorff's Annal. t. xl. p. 353.

‡ The following remark may not be entirely superfluous, viz. according to G. Rose, arragonite is formed in a higher temperature only in the moist way, but calcareous spar is formed in the dry way. Thus carbonate of lime crystallizes from a state of fusion under strong pressure only in the form of calcareous spar. Arragonite exposed to a slight red heat is easily converted into calcareous spar.

If the melted nucleus of the earth be the common seat of the volcanic activity of the whole earth, subterranean communications subsist between all volcanos. The existence of such communications cannot be doubted. Immediately after the earthquake which overthrew *Caracas*, there followed the great eruption of the volcano of *St Vincent*, and the earth no longer trembled at *Venezuela*. When the dense, black column of smoke, which, in the year of 1797, had issued for several months from the volcano near that city, disappeared, the cities of *Riobamba*, *Hambato*, and *Tacunga*, 280 English miles distant, were at the same hour destroyed by a violent shock.* Other instances of this kind will be mentioned afterwards.

Andrea Lorenzo Curbeto's description of the great volcanic eruption in the island of *Lancerote*, for which we are indebted to Von Buch,† also shews how for six years, from 1730 to 1736, the gaseous fluids in the interior found new vents in all directions, sometimes here and sometimes there, and yet were not capable of preserving a single one permanently open. Sometimes two or three openings were formed at once with a tremendous crash accompanied with flames, (?) which alarmed the whole island. At one time three apertures united suddenly into one very high cone; lava flowed out below and reached the sea. If, says that acute geologist, the unhappy *Lancerote* had, like *Teneriffe*, possessed a volcano, perhaps not one of those numerous cones would have been thrown up, and probably not a single village would have been destroyed.‡ He thinks it highly probable that this eruption took place entirely from one great rent.

* Von Humboldt Reise, t. 1. p. 498.

† Loco cit.

‡ Von Buch supposes that only the gaseous matters, but not solid substances, viz. lavas, slags, rapilli, and ashes, proceed from the focus of the volcanic phenomena. He observes that these masses always shew themselves to be of a nature corresponding to the rocks out of which they are ejected.

We must not forget that Von Buch was at that time still attached to Davy's hypothesis, which ascribes volcanic phenomena to the combustion of the metals of the alkalies and earths, and which does not require us to suppose the origin of volcanic action to lie at any great depth. It is in-

During the violent eruption in the low country of *Skaptar Jokul* in *Iceland*, in 1783, which suddenly brought up the most enormous masses to the surface, the lava burst forth at three different points, more than two geographical miles distant from one another, and spread over a surface in the plain,* which is supposed to equal in extent sixty geographical square miles. This mass is so considerable as to surpass in magnitude that of *Mont Blanc*.† Under almost the whole of *Iceland* there is a volcanic furnace, which communicates by many apertures with the surface. The masses of melted matter, therefore, seek an outlet at various points, and many places are mentioned, at which the lava has only been ejected once within historical times. The volcanic phenomena are not confined to the island alone, they also break through in the neighbouring sea. In January 1783, such an eruption took place in the sea, eight geographical miles from *Cape Reikianes*, several islands were raised, and great quantities of pumice and light slags were floated on the coast. In June the whole island was shaken by earthquakes. The submarine eruption discontinued, and at a distance of fifty geographical miles the grand eruption of

deed, very different, according to the hypothesis which we are endeavouring to defend. In this the seat of the volcanic actions is supposed to be identical with the place where the elastic forces producing them act. The connection between the lavas, and the slags, rapilli, and ashes resulting from them, and the rocks at the surface, would only then shew that the same material which composed the rocks, raised at a former period, and now spread over the surface, has also served for the production of the more recent volcanic formations. But it still remains to be taken into consideration, that aqueous vapour, generated in the lowest point of the volcanic focus, possessing its maximum of elasticity, and heated to the melting point of lava, or above it, is capable, as we have already said, without the assistance of any other power, of converting fusible rocks into a state of hydro-igneous fusion.

* See Om Tordbranden paa Island i Aaret 1783, ved Student Soemund Magnussen. Kort beskrivelse over den eye Vulkans, Ildsprudning i Vester Sköptefells Syssel paa Island i Aaret 1783 of Magnus Stephen sen. Kiöbenhavn 1785. Sir G. Makenzie's Travels in Iceland. Ganlieb's Island, 1819, p. 64. Th. Gliemann geogr. Beschreibung von Island, 1824, p. 107. Penant le Nord de Globe, t. i.

† Berghaus Almanac for 1838, p. 75.

Skaptar Jokul commenced. On the 13th June 1830, a similar submarine eruption was repeated.*

The immense masses of lava ejected from a single volcano, and the enormous extent in which volcanic actions are felt at the same time, scarcely leave room to doubt that every active volcano is in immediate communication with the whole melted matter in the interior. In this manner alone can it be conceived, how, for instance, the masses ejected at different times from *Vesuvius* vastly exceed the whole bulk of the mountain,† while the latter seems upon the whole to undergo no diminution, for the falling in of its cone at one period appears to be balanced by the accumulation of ashes at another.

If a rent reaching from the surface to the melted matters in the interior be of great length, but not open throughout its whole extent, the first eruption will take place where there is the least resistance.

If this channel become obstructed, the volcanic fire will seek another vent.‡ Violent concussions may open new fissures § and close old ones, by which frequent changes may be produced in the channels of the lava and water. Fissures obstructed by lava are closed so firmly as to be incapable of being re-opened; new ones, therefore, are formed. Thus it is, at least, if a volcano produce eruptions from its sides. If it happen that a wide and lasting vent be formed, all partial workings in the neighbourhood will cease. A similar combination, although on a somewhat limited scale, is presented by groups of mineral springs, especially of hot springs. In such groups new channels

* Journ. de Géologie, t. i.

† This was remarked even by the ancients; and Seneca, Letter 79, after stating the difficulty, solves it by remarking, that the fire of the volcano, “in ipso monte non alimentum habet, sed viam.”—Daubeny on Volcanos, p. 155.

‡ Thus the interior of the crater of the *Peak of Teneriffe* shews it to be a volcano, which for thousands of years has thrown out fire only from its sides. V. Humboldt, Reise, t. i. p. 195.

§ According to the inhabitants of *New Andalusia*, the soil in various districts in their province has become more and more arid, in consequence of the frequent earthquakes with which they are visited from time to time. V. Humboldt, Reise, t. ii. p. 21.

are seen to open, new springs to rise, and old ones to close. The only difference is, that, as these changes are not accompanied with any violent action, as is the case with volcanos, they require a greater length of time for their accomplishment.

We have, in the preceding inquiries, as yet only supposed the admission of water from the sea. But this does not seem always to be the case, even in volcanos situated near the sea. According to Hamilton,* the water of the springs and wells of *Torre del Greco* diminished so much a few days before the great eruption of *Vesuvius*, on the 15th June 1794, that the corn-mills at the principal spring were nearly stopped, and it was daily necessary to lengthen the ropes in the wells, in order to reach the water. Some wells dried quite up, and on the morning of the 12th June, at *Resina*, a subterranean rumbling noise was heard after a heavy rain. Monticelli and Covelli † relate that, before the great eruption of this volcano in 1822, at the beginning of January, the springs at *Resina*, *St Jorio*, and particularly in the places in the immediate vicinity of *Vesuvius*, diminished perceptibly. ‡ Monticelli observed similar phenomena before the eruption in 1813, and he thinks that, in general, they are a sure sign of one. It is hardly to be doubted that rents were opened by the earthquakes, through which the water descended to greater depths, accumulating, perhaps, in great caverns, and from thence found its way to the source of the volcanic action.

We find considerable accumulations of water in all mountains traversed by numerous fissures. We will only now men-

* Phil. Trans. for 1795, p. 73.

† Loco cit. pp. 12 and 63. See also Monticelli, in Leonard's Taschenbuch für die gesammte Mineralogie, vol. xiv. p. 87.

‡ The same was observed twenty-three days before the earthquake in *Calabria*; and also in the *Peak of Teneriffe*, in 1706. Von Humboldt, Relat. Hist. t. i. p. 393. In *Iceland*, this phenomenon was observed before the terrible eruption of *Skaptar Jokul*, in 1784. In general, in volcanic districts, the porous and much fissured rocks swallow up the rain-water, and carry it down to very great depths. Von Humboldt gives this as the cause of the extreme aridity which reigns in most of the *Canary Islands*, notwithstanding the height of the mountains, and the mass of clouds which travellers always see collected over this Archipelago. Reise, t. i. p. 173.

tion the western declivity of the *Teutoburger Wald*, in which such considerable rivers have their source; the *Jura* mountains; and the *Gemmi*.* The volcanic inundations, of which Von Humboldt gives such extraordinary examples,† are an additional evidence of the existence of such great subterranean accumulations of water, in the vicinity of volcanos. Lastly, we have, further, examples of volcanos coming into action after violent storms of rain; for instance, the *Mer-Api*, in *Java*.‡ In the *Andes* of *Quito*, the Indians imagine they have observed, that the quantity of percolating snow-water increases the activity of volcanos.§ Can it, then, any longer be doubted, that the proximity of the ocean is by no means a necessary condition in the production of volcanic phenomena? But all that has been said respecting the channels by which the sea-water is admitted to the volcanic focus, holds equally good with respect to those admitting springs or rain-water; only with this difference, that, in the more lofty volcanos of *America*, the volcanic focus may be imagined much higher, and yet columns of water of considerable pressure will not be wanting, provided those accumulations of water be situated at a great height in the mountains.

The same power by which masses of lava are forced up, sometimes so as to reach the surface and flow over it, or in other cases becoming solidified in their channels, will also raise whole mountains. These elevations may take place through

* Von Humboldt (*Reise*, t. iii. p. 229), mentions several rivers which lose themselves in the gneiss rocks. When these gneiss mountains were up-raised, considerable caverns may have been formed, which were afterwards filled with water.

† *Annal. de Chim. et de Phys.* t. xxvii. p. 123. This circumstance, however, must be considered, that the strong heat over the active volcano dilates the atmosphere, and produces a rising stream of air. The consequence of that is an influx of air from all sides. But this air is accompanied with moisture, which, rising with it, is condensed in the higher regions of the atmosphere, and falls down in showers. Therefore, an active volcano affords not only water, which immediately issues from its interior, but it also deprives all the environs of water. Du Cart sur les inondat. Volcaniques. *Journ. de Physique*, t. xx. p. 103.

‡ *Memoir of the Conquest of Java*. London, 1815, p. 40.

§ Von Humboldt's *Reise*, t. i. p. 263.

rents of more or less considerable width; and partly form dykes, or mountains of some magnitude; or raise up or break through the upper strata of the earth. Thus Von Buch* informs us that on the island of *Lancerote*, during an eruption in 1730, a rent was formed above two German miles in length, on which about twelve conical hills had risen, whose summits were from 600 to 800 feet in height. In like manner basaltic cones (also even porphyritic and granitic hills), are situated in a line and of which two or more are connected by rents, which are filled up by basalt. Remarkable phenomena of this kind are seen near *Murol* in *Auvergne*.†

We have abundance of proofs of the rising of masses of melted or at least semifluid matter,‡ out of the interior of the earth, in the filling up of dykes with compact crystalline rocks, in all of which, as in the rocks of undoubted volcanic origin, felspar forms a necessary and principal ingredient.§ We find these rocks in contact with all the stratified and superficial formations, even with those which are going on at the present day. But similar masses, which have evidently flowed in streams from craters, are also found in positions which shew that they must have risen from the interior of the earth, after the formation of the stratified rocks, and found their way into fissures, which in many cases do not reach the surface. Thus, granite, syenite, trachyte, the porphyries, the greenstone, and so on, up to the basalts, form dykes in the stratified rocks as well as in one another. They also not unfrequently appear in beds between

* Leonard's Taschenbuch, 1824, Abth. ii, p. 439.

† Leonhard die Basalt Gebilde, t. i. p. 408.

‡ Cones of basalt, trachyte, and phonolite, whose inclination is often very considerable, cannot have risen in such a thin liquid state, as that in which lava issues from volcanos; for, according to the observations of Elie de Beaumont already mentioned, lava streams having an inclination of only 6° cannot form a continuous mass. See on this subject Leonhard, loco cit. t. i. p. 417, &c.

§ Felspar may certainly be considered as a characteristic sign of an igneous origin in rocks, as this mineral is never found in rocks, in the formation of which the action of volcanic power can be proved to have been wholly excluded.

the strata of the Neptunian rocks. Granites have been forced up to the surface at the most widely different periods; we find them most commonly in clay-slate, and in the greywacke formation, in gneiss and in mica-slate, and they are sometimes connected with other more considerable masses of granite. Even after the formation of the oolitic and chalk groups, they have been ejected; but there are no granitic dykes described as intersecting these rocks. The stratified rocks are usually altered in the immediate vicinity of masses or dykes of granite; and their stratification becomes indistinct and confused. The porphyries, like the granites, exist as independent formations; but these are not so frequent or so extensive, and are more frequently in contact with more recent stratified formations than the granites. The trap rocks traverse all the stratified rocks from the gneiss and greywacke group, at least to the oolites inclusively. The basalts are found in all formations, from the transition and secondary rocks to the lignite inclusively, nay, in the newest formations.*

In general, some alteration in the adjacent rock and some new mineral productions,† are found where such masses have been forced up, and large and small fragments of the rock are not uncommonly found firmly imbedded in the latter. We may here, by way of example, mention the conversion of compact limestones into marble, exactly as Hall changed limestones by heating them in close vessels or under pressure; and again, the disappearance of the black colour and the bitumen in the coal-sandstone.‡

* Leonhard's Basalt Gebilde t. ii. p. 6, &c.

† The adjacent rock, heated by the melting mass, might, by their both cooling very slowly together, give rise to the production of crystalline substances (as hornblende, felspar, mica, by the contact of granite with clay-slate). But the rock would probably also take up substances from the melting mass (alkalies) which would serve as a flux.

‡ The combustion of beds of brown coal seems also to have been effected by igneous fluid masses which had risen from the interior. Thus the remains of such combustions always occur in *Bohemia*, according to Dr Reuss (*Nöggerath Ausflug nach Böhmen*. Bonn. 1838, p. 171), in the neighbourhood of basalts, and these phenomena are so enormous, that they cannot be considered as caused by accidental combustions.

The conglomerates which frequently surround these volcanic masses, and which are not confined to the basalts and trachytes, but are also found accompanying the greenstones, porphyries, and granites, Von Buch considers to be produced by the friction of the rising matter against the rock; and their existence is a further proof of the pyrogenetic origin of these masses.

Other phenomena lead us also to infer that crystalline rocks have risen in a melted state. If, for instance, such rocks are separated by rents, crystals are often found in them, broken through the middle, and both pieces are imbedded in the separated rocks. Thus, my friend Prof. Nöggerath has observed that many of the larger crystals of glassy felspar in the trachyte of the *Drachenfels* are broken through in this manner, and that the one piece is displaced several lines from the other. He observed the same phenomenon more frequently in the porphyritic granite near *Göpfersgrün* in the *Fichtelgebirge*.^{*} The olivine in the basalt of *Burzet* in *Vivarais* presents the same appearance, according to Scrope,[†] and the separated portions of crystals exactly correspond. Faujas observed among the basalts of the bridge of *Bridon* adjacent columns, with included fragments of granite broken through, in consequence of the formation of the columns. All these phenomena prove that these crystalline rocks must have been still soft, after the imbedded crystals had arrived at the stage of perfect solidification, and that the breaking of the crystals is a consequence of cooling.

The occurrence of arragonite in the fissures and cavities of crystalline rocks, basalt, for instance, seems also, according to the above-mentioned experiments of G. Rose, to prove, that these rocks were at least still hot, when cold solutions of carbonate of lime penetrated into the fissures.

Lastly, instances of the formation of dykes of volcanic matter at the present day, offer a further proof, if further proof be necessary, of their igneous origin, and the accounts given of the

^{*} Nöggerath loco cit. p. 71. See also Goldfuss and Bischof, *Physikalisch-statistische Beschreibung des Fichtelbirges*, t. ii. p. 114.

[†] Consider. p. 136.

recent eruptions at Ponohohoa in *Owhyhee*,* establish the possibility of eruptions through rents.

If alterations in the adjacent rocks, or other phenomena already mentioned, are not observed, we may infer that the elevations have taken place in a solid state. Notwithstanding this solidity, the highly elastic and exceedingly hot vapours may certainly cause considerable chemical alterations in the elevated masses, as well as in the adjacent rocks.

It is impossible to determine any regular order of succession in the elevation of the pyrogenetic rocks. They occur in every period of the stratified formations. Older ones have very commonly received those of more recent date into their fissures. There scarcely exists a single unstratified rock which is not somewhere to be found filling up dykes in granite. Basalt-dykes traverse many unstratified rocks, such as trachyte, conglomerate, and others. In *Iceland*, tufa is found alternating with slaggy lava; and dykes of a porous trachytic rock traverse the tufa of *Stromboli* and *Vulcanello* in the *Lipari Islands*, &c.†

Masses of melted matter will break through the bottom of the sea more easily, because resistance is there the least considerable. To this may be ascribed the frequent elevation of islands from the bottom of the sea, not only in historical times, but also at the present day, and under the eyes of observers, in whom the utmost confidence may be placed. The most extraordinary and instructive island in this respect is *Santorin*, because it unites the whole history of volcanic islands and islands of elevation. A more beautiful, regular, and perfect crater of elevation is not to be found, than in the space which is almost entirely surrounded, by the inner circle of *Santorin* (which encompasses more than one-half of it), and by its continuation as exhibited in the islands of *Therasia* and *Aspronisi*.‡ Here it is probable that the clay-slate was broken through and up-

* Poggendorff's Annal. t. ix. p. 141.

† De la Beche, Handbuch der Geognosie Von v. Dechen. Berlin, 1832. Abschnitt xi.

‡ Von Buch in Poggendorff's Annal. v. x. p. 172. See the drawing in his splendid atlas, and the sketch in these annal. v. xxiv. p. 1.

raised. These islands, therefore, cannot have been raised one after another; on the other hand, history and tradition inform us that the island ceased in its endeavours to create a new island in the centre of this crater of elevation. 184 years after the birth of Christ, the *Island of Hiera* (now called *Thira*) was formed, and since that, as it seems, no new island has been raised in its centre. In 1427, the *Island of Thira* was destroyed. In 1573, the *Little Kameni* was thrown up in the centre of the basin, accompanied with flames, smoke, and pumice; and between 1703 and 1709, the *Big Kameni*, which still continues to rise, was formed. Lastly, in the present moment, a new island is about to appear to the east of the *Big Kameni*, on the coast of *Santorin*, according to the prediction of *Santorin*,† (*Nauplia*), the inhabitants of the island assert, that it will lie at the depth of 90 feet; in 1703, it was on the surface; and at present the island is still on it. According to later accounts, the island of this bank continues to rise so rapidly, that without interruption in its progress, it will soon be able to lay claim to the denomination of *Island*. In 1713, it is said an island arose at the mouth of the *Venice*, accompanied with flames, smoke, and shocks. This phenomenon, which continued for some time, drove away the inhabitants from the adjacent islands. In the two years a similar occurrence was observed at the island was thrown up under the same circumstances. The two islands are now, as the neighbouring islands are cultivated.||

* Von Hoff, Geschichte der natürlichen Veränderungen der Erde, t. ii. p. 137. For an account of some crater-ships, see Gendendorff's Annal. v. xxiv. p. 101.

† See the account of Father Bourignon in Raspe's Voyage en mare natis insulis 1763, p. 48.

‡ Allgemeines Organ für Handel und Gewerbe, Jameson's Phil. Journal, vol. xxi. p. 175.

|| Justi's Geschichte des Erdkörpers, p. 135.

From Leop. Von Buch's instructive exposition of the nature of volcanic phenomena,* which, together with the careful works of Von Hoff, contain a critical compilation of all cases yet known of the production of new mountains and islands by volcanic action, we will borrow only the following examples of recent date. The first I shall mention is the island of *Sabrina*, near *St Miguel*, in the *Azores*, which is celebrated for the many islands that have attempted to rise in its vicinity, and which made its appearance on the 13th or 15th June 1811; it began to disappear in October, and towards the end of February 1812, steam was only occasionally seen to rise out of the sea at the spot where the island was formerly seen.† Secondly, The rising of a new island near *Unalaschka*, in May 1796, which not only remained, but, up to 1806, had increased in circumference, as well as the peak in height. It required six hours to row round it, and rather more than five hours to ascend in a direct line from the shore to the summit of the peak.‡ The creation of both these islands was preceded by violent earthquakes, and columns of smoke, which ascended from the sea, whilst stones were thrown to a great distance. Of *Sabrina* this surprising circumstance is related—that the stones, on leaving the sea, were black, but suddenly became red hot when they emerged from the columns of smoke. Tillard found on this island the skeleton of a shark so calcined, that the bones fell to powder on lifting it up. Of the other island it is only said, that during the night fire rose, which was sometimes so bright, that all objects were distinctly visible in *Unalaschka*, at a distance of twenty leagues. Smoke continued to rise for four years.

Phenomena of this kind have taken place still more recently among the Molucca Isles, as we are informed by Prof. Rein-

* Poggendorff's Ann. v. x. p. 1 and following, p. 169, 345, and 514 and following.

† See also V. Humboldt's Reise, t. i. p. 254, and t. iii. p. 6. It is worthy of remark, that the small island of 1720 has reached exactly the same height as *Sabrina* attained in 1811.

‡ It was, consequently, more than 1000 feet high. Unfortunately the depth of the sea at that place is not given. But it certainly offers an example of one of the greatest elevations of the present day.

wardt.* Near the active volcano of *Gonung Api*, in the group of the *Banda Islands*, a considerable mass of black rock rose up in a bay, out of the sea, without any noise. When Reinwardt visited this extraordinary spot in 1821, he found it still very hot, and the newly raised mass sent forth boiling hot vapours. A precisely similar occurrence took place on the Coast of *Ternate*. On *Lancerote* also, on the 31st August 1824, after several days of violent earthquakes, accompanied with a subterranean thunder like noise, a new volcano burst forth with a terrific crash, emitting streams of fire, so that the whole island was illuminated, and throwing up so many red hot stones and fragments of rock, as to form a mountain within twenty-four hours.†

The last occurrence we shall mention, and which is still fresh in our memory, namely, the volcanic island which appeared in July 1830, in the *Mediterranean*, between the south-west coast of *Sicily* and *Pantellaria*, shews, that these phenomena may take place in two different ways. New islands may be formed in the sea either by the elevation of solid rock, by violently breaking and raising up the original strata, or merely by the heaping up of the loose masses which are ejected.‡ This event was of the latter description, and in its ephemeral existence exactly resembles the above-mentioned case in the *Azores*. Under which of these forms such volcanic productions appear, may depend on the nature and thickness of the rocks to be broken through, on the depth of the sea at the place of the eruption, and the strength of the volcanic force. However, the visible part of this island may, perhaps, as is the case with many others, only have been the summit of a peak situated in the centre of a crater of elevation, which remained buried in the sea, similar to the cones of many land volcanos, which, if they had been situated in the sea, would have been unable long to withstand the action of the waves, as is the case with most of these islands. Hoffman,§ who approached very near to this island, shortly after its appearance, saw quite plainly, that it was nothing else than the

* De incendiis montium igni ardentium insulæ Javæ, &c. disputatio geologica. Auctore van der Boon Mesch. Lugduni, Batav. 1826.

† Annal. de Chim. et de Phys, t. xxvii. p. 382.

‡ See, on the contrary, Von Humboldt in his Reise, t. i. p. 254, note.

§ Poggendorff's Ann. t. xxiv. p. 75.

edge of a crater, the walls of which were gradually raised above the surface of the water by the materials ejected from it. From this crater vapours rose uninterruptedly with great violence, yet without noise, which were succeeded by the ejection of slags, sand, and ashes. The appearance of this island was also preceded by a noise resembling thunder, and by the elevation of a mass of black coloured water to a height of eighty-two feet, columns of smoke rising at the same time to a great height. The accounts leave us in uncertainty respecting one of the most important circumstances—whether fire rose out of the crater or not. However, Hoffman and his companions are inclined to the more probable opinion, that this volcano vomited no fire, and that what some observers took for flames, was only the *fé-rilli* in the smoke.* Lightning, caused by the electricity excited by the rapid evaporation, was observed there, as it is during the eruptions of *Vesuvius* and other igneous mountains. At the end of December 1830, this island, which was 2100 feet in circumference, and the highest point of which rose 210 feet above the sea, shared the fate of *Sabrina*, and disappeared. From the bottom of the sea it had risen between 700 and 900 feet; and from what depth below, may be conjectured from the calculations previously given.

Thus, then, the rising of islands out of the sea is a well authenticated fact, and if we should for a moment be left in doubt concerning the cause of this phenomenon, by the appearance of steam in the presence of the sea-water, yet the evolution of aqueous vapour from volcanic islands, enclosed on all sides by solid rock, seems to dispel such doubts.

Examples of elevations on land in historical times are much more rare. Of these we are only acquainted with the elevation of *Monte Nuovo* near *Puzzuoli* in 1528, which rose 400 feet in about three days; that of *Monte Rosso* near *Catania* in Sicily, in 1669, which rose to a height of 820 feet in about four weeks, and that of *Jorullo*, which rose to a height of 1480 feet above the plain, in one day, on the 29th September 1759.†

* Without exactly wishing to generalize, this circumstance is yet sufficient to render us distrustful in judging of descriptions of similar phenomena in which flames are so often mentioned.

† Von Humboldt *Nouv. Espagne*, v. ii. p. 290. See Burkart *loco cit.* vol. i. p. 226.

These are also formed, like the volcanic islands, in two different ways. The *Monte Nuovo* was formed by the accumulation of the loose masses ejected from the volcano, whilst mountains of basalt, trachyte, phonolite, &c. which are so abundantly scattered over the surface of the earth, have been formed by the upraising of solid rocks.*

Vesuvius, or rather its cone, seems also to present an example of an elevation in the historic area. Its formation perhaps does not go farther back than the period of the famous eruption of 79 after the Christian area, in which *Herculaneum* and *Pompeii* were destroyed; for ancient writers never speak of the mountain as consisting of two peaks, which they probably would have done, if the *Monte Somma* had stood, as at present, distinct from the cone of *Vesuvius*.† It is also remarked that the distance mentioned in ancient writers, as intervening between the foot of *Vesuvius* and the towns of *Pompeii* and *Stabiae*, appears to have been greater than exists at present, unless we measure it from the foot of *Monte Somma*, so that this affords an additional probability, that the latter mountain was then viewed as a part of the former, and that no separation between them had at that time occurred. We may also be sure from the semicircular figure which the southern escarpment of the *Monte Somma* presents towards *Vesuvius*, that it constituted a portion of the walls of the original crater; and Visconti, it is said, has proved by actual measurements, that the centre of the circle, of which it is a segment, coincides as nearly as possible with that of the present crater. There seems, therefore, little room to doubt, that the old mouth of the volcano occupied the spot now known by the name of the *Attrio del Cavallo*, but that it was greatly more extensive than this hollow, as it comprehended likewise the space now covered by the cone, which was thrown up afterwards in consequence of the renewal of the volcanic action that had been suspended during so many ages. This view likewise tends, as it seems, to reconcile the accounts

* The late investigations of Buch, Dufrenoy, and Elie Beaumont, shew that the *Monte Nuovo* is a crater of elevation, therefore not entirely or chiefly composed of loose masses of ejected rocks.—*Edit.*

† Daubeny, a Description of Active and Extinct Volcanos, &c. p. 144. See also Von Buch in Poggendorff's Ann. t. xxxvii. p. 173.

which ancient writers have given of the structure of the mountain, antecedently to the period before mentioned.*

As for the mode of action of the vapours, it is indifferent whether they have to contend with loose and unconnected, or with melting masses, only that the former are propelled into the air like cannon balls,† and falling into a parabolic curve, accumulate and produce a mountain, whilst the latter remain at the height to which they are borne up by the elastic fluids.

In elevations of the latter description, the vapour cannot escape through the uplifted mass. This mass is supported by the elastic force of the vapour, cools gradually, and then remains, as it were, wedged in between the strata it has broken through. But according to Von Buch's‡ observations on *Palma* and *Gran Canaria*, it may happen, that the vapour bursts forth from the centre of the mass it has raised, and thus exposes its interior. Such a crater would thus be the effect of the elevation of the island, for which reason he gives it the name of crater of elevation (*Erhebungs Krater*), to distinguish it from the craters of eruption, by which true volcanos open a communication with the atmosphere.

Further, this philosopher has pointed out,|| that volcanic cones cannot be generated by the building up of streams of lava. He infers this from observations made by Elie de Beaumont, and which have been already alluded to. This philosopher measured the mean inclination of about thirty lava-streams of *Etna*,

* See the Historical Notices given by Daubeny, loco cit. p. 145 and following.

† V. Humb. (*Reise v. i. p.* 226) calculates from the time the stones thrown out during the lateral eruption of the *Peak of Teneriffe*, on the 9th June 1798, took in falling (which according to *Cologan* was from twelve to fifteen seconds, reckoning from the moment they reached their greatest height), that they were projected to a height of more than 3000 feet. In some similar observations made by Von Humboldt during the eruptions of *Vesuvius* in 1805, he satisfied himself that such observations are capable of a great degree of exactitude. Similar calculations made by other observers, give still greater heights. The maximum height of such projections was observed at *Cotopaxi* by La Condamine (*Voyage à l'Equateur*). He saw propelled laterally, a block of about 1000 square feet, to a distance of nearly $1\frac{1}{2}$ geographical miles.

‡ *Abhandlungen der Berliner Acad.* loco cit. p. 58.

|| *Poggendorff's Annal.* t. xxxvii. p. 170, &c.

and of a great many of *Vesuvius*, and found that a stream having an inclination of 6° , or even more, forms no continuous mass. Such a stream inclines too much to be able to attain more than a thickness of a few feet. When its inclination is only 3° or less, the mass may be spread, and accumulated to a considerable height.*

Lastly, we have to notice the upraisings which are the consequences of earthquakes, and often extend to large islands and whole tracts of country. Elevations of small compass, accompanied by partial depression, which is no doubt merely a consequence of the elevations, were observed before,† and during‡ the famous earthquake of *Lisbon*. Small elevations also took place during that in *Calabria* §. The commissioners who were employed to make observations of the earthquakes in the county of *Pignerol*, relate, that the very day (2d April 1808), when one of the most violent shocks was felt, the masting engine at *Toulon* was elevated more than an inch.|| This observation is worthy of note, as it shews that many effects of earthquakes may often take place at great distances from their seat, which, owing to their minuteness, may escape observation, unless casually discovered. For accounts of elevations of a more considerable kind in equatorial countries we are indebted to Humboldt. The elevations in the island of *Lancerote*,¶ and those on the coast of *Cumana*** are of this kind.

The most remarkable instance of the elevation of great tracts of country of late years, is that which took place in *Chili*, on the 19th November 1822. For the account of this important phenomenon we are indebted to Mrs Maria Graham, a well informed observer.†† After violent earthquakes, which were felt

* Vide Memoir of Elie de Beaumont, in vol. xx. p. 376, &c. Edin. New Phil. Journ.; and Description Geologique de la France, t. iv.

† Palassou Mém. pour servir à l'Histoire Nat. des Pyren. p. 260.

‡ Philos. Trans. t. xlix. p. 417. § Jour. de Phys. lxii. 1806. p. 264.

§ Idem, t. lxxvii. 1808. p. 308. ¶ Relat. Hist. t. i. p. 188.

** Ibid. t. ii. p. 279.

†† Geol. Transact. v. i., Sec. Series, part ii. p. 413. Mr Greenough felt disposed to call in question the observations of Mrs Graham, but she has defended her statements very creditably, and has been supported by Mr Meyen, Berghaus Annal. der Erdkunde, t. xi. p. 129.

through an extent of country 1400 English miles in length, and during which it appeared as if the soil was suddenly raised and immediately sunk again, or as if the earth had an undulating motion from north to south, accompanied with a noise like the rushing of steam, the whole coast for an extent of about 100 English miles actually rose between three and four feet within twenty-four hours.* In all the small valleys the earth in the gardens was disturbed, and sand and water rose in quantities through the cracks. The granite rocks near the coast, which are traversed by small parallel dykes, shewed many narrow rents parallel to the old ones in some instances. The former were traced one mile and a half inland. The phenomena which most forcibly arrested the attention of Mrs Graham, were evident marks of this coast having been raised in a similar manner by earthquakes in former times, and indeed to a height of fifty feet above the sea level.

The latter phenomena are so much the more important the more frequently they occur. We can, therefore, have no difficulty in admitting most earthquakes to have been the causes of such elevations. Many coasts, as is well known, bear evident marks of having been raised in former times. Thus Vetch† observed on the coast of the island of *Jura* in Scotland six to seven terraces one above another, the lowest at the level of the sea, the highest about forty feet above it, all covered on their horizontal surfaces with pebbles like those which the sea still throws up. Mr Smith of Jordanhill has also pointed out, that in a former time an elevation of the west coast of *Scotland* has taken place.‡ Peron noticed a similar phenomenon on the coasts of some islands in the neighbourhood of *Van Diemen's Land*. Many other instances of this kind occur, which present

* Fr. Place also confirms this account of the extent of the elevation, in Journ. of Sc. No. xxxiii. p. 36. According to the reports in the Ann. de Chim. et de Phys. t. xxvii. p. 350, two volcanos, in the neighbourhood of *Valdivia*, presented a sudden eruption with a loud noise, and illuminated the whole country for some seconds, but they soon subsided again. At the same time a slight shock was felt in that town.

† Geological Trans. Sec. Series, v. i. part ii. p. 416.

‡ Phil. Mag. v. x. p. 136; Jameson's Phil. Journal, vol. xxv. p. 378; and Mem. Wernerian Soc. vol. viii. part. i. in the press.

traces of elevations, some of them perfectly incontestable,* others very probable.† In conformity with this are also the assertions of the inhabitants of *Otaheite*,‡ and those of the *Molluccas*,§ that their islands still continue to rise.

The latest earthquakes, which, in the month of February 1835, destroyed a great part of *Chili*, (*Conception*, and many other towns), offer also evident proofs of elevations occasioned through their agency. Some days after this devastation the sea did not rise to its ordinary level, the difference amounting to four or five feet in height. This difference decreased gradually; in the middle of April it was still two feet. The fact that the island of *Santa Maria* has risen nine feet, proves the actual elevation of the country. Near *Tubul*, south-east of *Santa Maria*, the country has risen six feet, and the island of *Mocha* seems to have risen about two feet.||

The gradual elevation of *Scandinavia* and *Finland* is peculiarly interesting. More than a century ago Celsius called attention to this phenomenon, and endeavoured to account for it by a gradual sinking of the level of the *Baltic*. Playfair,¶ however, remarked, as early as the year 1802, that an elevation of the land may be assigned as the cause of this phenomenon with more probability than a sinking of the water. This supposition, he thinks, accords with Hutton's theory, according to which the continents have been actually raised by subterraneous powers, and are even now supported by them in their place. Lastly, Von Buch,** without having seen Playfair's work, gave his opinion, "that the whole country, from *Frederickshall* in *Sweden* to *Abo* in *Finland*, is in the act of rising slowly and insensibly." The rising of the Gulf of *Bothnia* amounts, according to the observations communicated by Hällström, from 3. 71 to 4. 61

* Dolomieu Oryktol. Bemerk. über Calabrien. Frankf. u. Mainz 1789, p. 157.

† Brochi in Biblioteca Italiana 1821. Sept. Breislak Reisen in Campanien, t. ii. p. 115.

‡ Correspondence Astronomique, v. x. p. 266.

§ Poggendorff's Ann. t. ii. p. 444, according to Prof. Reinwardt.

|| Nautical Magazine, No. 49 and 51. March and June 1836.

¶ Illustrations of the Huttonian theory.

** Reise durch Norwegen und Lappland, t. ii. p. 389.

feet ; on an average 4. 26 feet during a century.* Beds of sea-shells, found sometimes 200 feet above the present level of the sea, as, for instance, on the sea-coast and on the islands of *Uddevalla*, as also on all the sea-coasts of the south of Norway, and which sea-shells consist of such kinds as are still found living at these places in the sea, prove how much the level of the *Baltic* has changed even during the time that the present testaceae have inhabited it.† But the rising seems to be very unequal at various places. In the north it is more considerable than in the south. On the eastern coast of the *Danish* islands of *Möen* and *Seeland*, *Lyell*‡ found no indication of a recent elevation of land. The first place along the whole coast of the *Baltic*, where an elevation is said to have taken place, is the town of *Calmar*. Beyond the *Swedish* coast, on the coast of *Finland*, the inhabitants are perfectly convinced either that the water sinks or the land rises. This remarkable phenomenon has excited a general interest among the Swedish naturalists, and caused continual exact observations of the marks inscribed on the shores of the Gulph of *Bothnia*. Thus *Nilson*§ thinks he has found convincing proofs that the most southern part of *Sweden* is sinking, whilst the remaining part is rising. He has also endeavoured to give probability to the supposition, that the sinking took place, and still takes place, not suddenly, but gradually. *Forchhammer*|| likewise alluded to similar phenomena, in order to prove that elevations in *Scandinavia* take place not only in different proportions, but that a depression is also going on. He infers from his observations, that the level of the coast of Denmark has varied in a different proportion from that of the *Swedish* coast, which he ascribes to the feeble earthquakes that have been felt so often in *Sweden*, but never in *Denmark*. He estimates, according to rough calculations, the elevation of the island *Bornholm* to amount to one foot in the course of a century.

If elevations of countries, in which volcanic actions are felt, and which are agitated by violent earthquakes, be produced, as is

* *Bruncrona* u. *Hällström* in *Poggend. Ann.* t. ii. p. 308.

† *Berzelius Jahresbericht*, 1826, p. 292.

‡ *Poggendorff's Ann.* t. xxxviii. p. 64.

§ *Berzelius Jahresbericht*, No. 18, p. 386, and *Poggendorff's Ann.* t. xlii. p. 472.

|| *Phil. Mag.* ser. iii. v. ii. p. 309, and *Poggend. Ann.* t. xlii. p. 476.

very probable, by the same causes as these phenomena, yet it is difficult to imagine these causes to operate in elevating countries where no such phenomena occur, or where, at least, they take place but rarely or to a small extent. The latter is the case in the *Scandinavian Peninsula*. That region has no active volcanos, no hot springs—even thermal springs bearing a temperature of but a few degrees higher than the mean temperature of the place, are considered as rarities; whilst, in other countries, they are of very frequent occurrence. All this proves that the crust of the earth in this country must be very solid, and traversed by comparatively few rents or fissures.

Berzelius assigns as the cause of this rising of the *Swedish coast*, the gradual cooling of the earth; and says: “Its diameter, in this manner, decreases, and the consolidated crust leaves either empty spaces between itself and the fluid mass, or sinks downwards. Being, however, of so large an extent that foldings and bendings must occur, portions must rise up on one side and sink on the other. This supposition seems to be supported by the sinking of the western coast of *Greenland*, and of an island situated in the Gulf of *Youghall*, a phenomenon which has been recently pointed out by Elie de Beaumont and Pingel. Klöden also has recently given much probability to the supposition of a sinking of the *Dalmatian coast*.*

We shall endeavour to shew in Part IV. what effect might be expected on the surface of the earth, if its solid crust should still continue to increase in thickness towards the interior by gradual consolidation of the fluid centre. Besides, I think that a sinking of the outer crust can scarcely be supposed to occur, but that it is much more probable that caverns should be formed at the moment, when the fluid mass becomes solid. At least the latter effect was seen in fusing two basalt balls, two feet in diameter, in which many larger and smaller cavities were found. I shall allude to these phenomena in another section.

If we take into consideration all that has been already said on ejections and elevations (*soulèvemens*) we shall be induced to adopt the following inferences. Masses of our earth, still in a fluid state, may be raised through and above its solid crust.

* Poggendorff's Ann., t. xliii. p. 361.

The rising of the lava in the craters of volcanos is a satisfactory proof of this circumstance. Solid rocky masses, strongly heated, may be pushed upwards during violent convulsions and elevations of the original rocky covering, or be thrown up in the form of loose masses, more or less heated. The not unfrequent rising of small islands from the bottom of the sea, and the elevations (*soulèvemens*) actually observed to take place in the continents, are evidences of these operations. All these phenomena are effects of forces, which develop their whole intensity in a very short time, often in a few moments. But large islands, and even whole countries may, in a very short time, be raised several feet, as was shewn in the cases of *Chili* and *Santa Maria*. On the other hand, *Scandinavia* presents us with an instance of an elevation which, compared with the preceding, takes place with extraordinary slowness.

Besides all these elevations which have been actually observed, other appearances occur, which lead us to infer that elevations have taken place previous to the existence of any record. These are the elevations of old volcanic masses, as basalt, trachyte, &c. their penetration into fissures, and the elevation of whole systems of mountains. In regard to the first, the conclusion may, as has been already shewn, be considered as well founded as it is generally possible to be, when drawn from phenomena which have taken place before any records were in existence. The similarity between these phenomena, and those which have taken, and still take place, before our eyes, render it extremely probable that they were produced by forces which were in operation for a very short period only. Changes in the contiguous rocks, and the imbedment of fragments of them in the volcanic rocks, render it also equally probable that these masses were raised in a fluid, or at least softened state, and either rose above the surface of the earth in the form of conical mountains, or remained adhering in rents of the rocks. These phenomena, then, belong entirely to the same class as the elevations of lava in volcanic craters. When, on the other hand, no changes are perceived in the contiguous rocks, when these have been simply broken through and upraised, when the broken masses consist of acute-angled fragments of all dimensions heaped one upon another, then we cannot assume that the elevations took place in a fluid or softened state.

sume that the solid crust of the earth in *Scandinavia* was 139,840 feet thick, that the expansion of this crust by heat takes place in the same ratio as in earthen ware; then, an average increase of heat of $2^{\circ}9$ R. during the space of 100 years, would be sufficient to effect an expansion of 4.26 $\frac{1}{2}$ feet in a stratum of the above-mentioned thickness. And this is the average ratio of the rising of that country.

Be the cause of the elevation of *Scandinavia* what it may, this circumstance is remarkable, that in the southern part of *Sweden*, where the country, according to Nilson's statement, sinks, secondary formations, viz. chalk, occur in great abundance, while in the north of *Sweden*, as well as in *Finland*, the gneiss-granite formation predominates. We must not, however, attach too much importance to the connexion which appears to exist between the elevation of the northern part of *Sweden* and the prevalence of the latter formation, as Nilson* says, "the chalk also lies on gneiss, and less frequently on greywacke. It is nevertheless remarkable that the granite island of *Bornholm*, which is situated opposite to the sinking coast of *Schonen*, is still in the act of rising, according to the observations of Forchhammer above alluded to.

As regards the sinking of countries, there is no difficulty in regarding it as the result of an elevation of neighbouring countries. Yet we can imagine many causes, independent of such elevations, which may produce depressions. It does not, however, lie within the scope of these remarks to enumerate these causes.

It remains to consider the elevations of whole systems of rocks, events which must have taken place prior to the existence of our records. There is doubtless no difficulty in also explaining these phenomena through the agency of steam. Elie de Beaumont,† however, is of opinion, that these elevations are a consequence of the inequality between the cooling of the interior and exterior of the earth. We shall examine this subject, after pointing out the laws that prevail during the cooling of large masses of fused matter.

* *Petrificata Suecana Form. Cretaceae*, &c. 1827. P. 81.

† *Poggendorff's Annal*, vol. xxv. p. 25.

diffused above, as it can be conveyed from the vapour below, and if the latter produce a continued elevation, the effect must inevitably be regressive. We can therefore conceive it possible, under the conditions stated, that the same force, viz. vapour of water, which, when in contact with a fused mass, developes its whole intensity in a short time, can produce only a gradual effect, when in contact with solid masses whose temperature is far below that of the vapour. We thus see the possibility of fused masses being raised by vapour in a short time, while solid masses may be raised very slowly by the same agent, and that the latter elevation may go on in a regressive ratio. Lastly, it is even possible that a gradual elevation of a solid mass may continue, although the elevating effect of the vapour has long ceased. For instance, if the subterraneous heating by steam continue, and if the heat, communicated to the surface of contact by condensation of the vapour, be diffused above more slowly than it is conveyed below, then it is clear that the solid mass supported by the vapour, will gradually be expanded.

These remarks have shewn that the operations of vapour, as an elevating force, may be very various as regards the relations of time and space, and that its effects depend not only on its own temperature, but also on that of the masses it has to elevate, on their relative conducting power, and lastly, on the capacity of the space within which its operations take place.

We can therefore understand how the slow elevation of *Scandinavia* may be a result of the operation of watery vapour, taking place in a diminishing ratio, and how therefore this phenomenon stands in close connexion with the original elevation of that country, which is principally composed of masses of igneous origin. We shall pass over the consideration of the question, whether this original elevation took place in a fluid or solid state, that is, whether in earlier times these masses rose suddenly and continued to rise more and more slowly as they gradually cooled, or whether this gradually decreasing ratio has always existed. We may, however, be allowed the remark, that the slow elevation which still continues when the operation of the vapour, as an elevating power, has long ceased, may be regarded, according to what has been stated above, as the result of an expansion produced by the caloric disengaged from the vapour during its condensation. For example, let us as-

beyond the immediate influence of the impelling force. In a former place, I have also shewn, that the seat of volcanic action may be looked for at depths far less than Stukeley supposes. But there is no reason to believe that earthquakes could go on at greater depths than volcanic actions. Supposing that the interior of the earth is still fluid, and that rents conducting water extend from the surface to the fluid nucleus, it is easy to conceive that the actions of the steam may be felt at very remote distances.

We have already pointed out the close connection which exists between earthquakes and volcanic eruptions. Von Humboldt, in his travels near the Equator, gives several examples of this. It may not be superfluous to refer here to what this illustrious philosopher asserts generally with regard to these phenomena, at the end of the 4th chapter of the 2d volume of Part I. Book 2.*

Every thing seems to shew that earthquakes are caused by the effort of elastic fluids seeking an outlet. On the coasts of the *South Sea* their action is often communicated almost instantaneously from *Chili* to the Gulf of *Guayaquil*, a distance of 600 geographical miles; and, what is very extraordinary, the shocks seem to be so much the stronger the greater the distance from the active volcanos. The granite mountains of *Calabria*, the limestone chain of the *Apennines*, the county of *Pignerol*, the coasts of *Portugal* and *Greece*, *Peru*, and the continent of *America*, furnish striking proofs of this assertion.† It might be supposed that the earth would be more violently shaken, the fewer the openings on the surface which communicate with the interior. At *Naples* and at *Messina*, at the foot of *Cotopaxi*, and the *Tunguragua*, earthquakes are dreaded only when vapours and flames do not issue from the mouth of the volcano. In the kingdom of *Quito*, the great catastrophe of *Riobamba* led many well informed persons to believe that this unfortunate country would be less often disturbed if the subterranean fire would succeed in destroying the dome of por-

* See also what Von Buch says on *Vesuvius*. Geognostische Beobacht. vol. ii. p. 129.

† Fleuriau de Bellevue, Journ. de Physique, t. lxii. p. 261.

phyry of *Chimborazo*, and if this colossal mountain should become an active volcano. At all times, analogous facts have given rise to similar hypotheses. The ancient Greeks, who, like us, attributed earthquakes to the force of elastic fluids, brought forward, in support of their opinion, the total cessation of earthquakes in the island of *Euböa*, after the opening of a chasm in the Lelantic fields.*

The intimate connection of earthquakes with volcanos is not less clearly proved by the direction which the former take. With the assistance of a simple instrument (the sismograph) invented by Cacciatore, and erected at *Palermo*, it was found in twenty-seven cases that the shock was propagated in a fixed linear direction, which coincided remarkably with the cardinal points. In nineteen cases the shocks were transmitted in a direction from east to west, corresponding with the situation of Mount *Etna*, the source of all these subterranean concussions, which lies directly to the east of *Palermo*. In four cases it was from south to north; but, for want of corresponding observations, the seat of these shocks cannot be determined; and it certainly does not seem to have been the effect of chance that three shocks, which were felt on the 9th February, 30th June, and 2d July 1831, travelled from the south-west to the north-east: for it was precisely in that direction, at a distance of about 70 Italian miles, that the small new volcano suddenly appeared in the sea, probably on the 2d July. The two latter shocks were also the very same that were felt with greater force at *Sciacca*, on the southern coast, opposite to the new volcano.†

On the other hand, Boussingault ‡ asserts that the most memorable earthquakes in the New World, which ravaged the towns of *Latacunga*, *Riobamba*, *Honda*, *Caraccas*, *Laguayra*, *Merida*, *Barquisimeto*, &c. do not coincide with any well established volcanic eruption. The oscillation of the surface, owing to an eruption, is, as it were, local; whilst an earthquake, which is not subject (at least apparently) to any volcanic eruption, extends to incredible distances, in which case it has also

* Strabo, lib. i. ed. Oxon. 1807, t. i. p. 85.

† F. Hoffman in Poggend. Ann. t. xxiv. p. 63.

‡ Annal. de Chim. et de Phys. t. lviii. p. 83.

been remarked that the shocks most commonly followed the direction of chains of mountains.

In favour of the hypothesis, that earthquakes are produced by aqueous vapour* penetrating to great depths, the following circumstances may be adduced. Firstly, as aqueous vapour is supposed to produce volcanic action, it must be presumed to be also the cause of earthquakes. Secondly, some hours before the first shock of the tremendous earthquake at *Algiers* and the neighbourhood, the 2d to 5th March 1825, which entirely destroyed the town of Blisa, all the springs and wells are reported to have been dried up.† Thirdly, earthquakes, though undoubtedly felt even in the centre of large continents, seem to produce their most frightful effects in countries not very far removed from the ocean. But, perhaps, earthquakes may

* A remarkable case which has taken place at the iron-foundry at *Saga*, proves, that shocks of the earth may be several times repeated by the effect of elastic fluids. A cylinder 14 feet in height, and 31,395 pounds in weight, was to be cast. The clay mould having been totally filled up by melted iron, the latter broke through the ground, and penetrated to the depth of 25 feet into the sandy soil, consequently 11 feet deeper than the lower part of the mould. Some time after an earthquake actually took place, which shook the whole building so violently, that the workmen feared it would be seriously injured. About half an hour after, an equally violent shock happened, and after more than 24 hours a third followed. The local circumstances of that iron-foundry lead to an explanation of these phenomena. There are at a depth of 23-24 feet under the ground of the said building, many inclined channels which communicate together, for the purpose of collecting the rain-water. Immediately after the shocks, watery vapours issued abundantly from the mouth of the channels. These vapours were evolved by the heat of the melted iron from the water, being in the ground about 2 feet below the bottom of the channels; and penetrated through the joinings of their brick-work. But these joinings being filled up with mud and sand, offered resistance, and consequently the vapours had to attain a certain elasticity before they were able to penetrate through them. It is, however, very probable that the vapours, bearing mud and sand with them, again stopped up the opening, when their elasticity gradually again decreased. During the shocks, the steam attained its greatest elasticity, and thickened the earth which surrounded the heated mass of iron; and this circumstance may have impeded a new afflux of water. Therefore, after the first shock, half an hour elapsed; and after the second, which still more obstructed the afflux of the water, even more than 24 hours elapsed before the third and latest shock took place.

† Berzelius, *Jahresbericht*, 1827, p. 310.

also be produced by gaseous exhalations in the interior of the globe. At least in many accounts of earthquakes, mention is made of the exhalation of gases from rents, produced by them,* and the smell of sulphuric acid and of sulphurous vapours, which indicate the presence of sulphuretted hydrogen.† These last may have occasioned also the destruction of the fish in the sea, and in lakes, during earthquakes; many instances of which are known. The bursting forth of flames from the earth and from the sea, which is so often mentioned,‡ also indicates the presence of inflammable gases. However, although this is corroborated by the fire-damp in mines, the disengagement of sulphuretted hydrogen while boring artesian wells, and the not uncommon exhalations of inflammable gas from the earth, yet it is difficult to account for their inflammation. This difficulty would disappear, if observation had found flames only to occur in really volcanic districts.|| But at any rate,

* Von Humboldt, *Reise*, t. i. p. 499. Von Hoff in *Poggend. Ann.* t. vii. p. 292, t. ix. p. 593, t. xxv. p. 76. V. Humboldt believes indeed, that during most earthquakes, nothing arises from the earth; but there are on the contrary, proofs that gases are often gradually evolved from the ground before and after the shocks. The uneasiness of small animals, or those whose organs of respiration are rather feeble, before and after earthquakes, lead us to infer this. Le Gentil (*Nouveau Voyage autour du Monde*, t. i. p. 172) has already observed, that animals living in holes, as rats, mice, reptiles, &c., commonly quit their abodes shortly before earthquakes. Crocodiles quit their pools in the *Llanos*, and remove to the continent, *Relat. Hist.* t. v. p. 57. Von Humboldt moreover relates that dogs, goats, and particularly hogs, which have a keen smell, and turn up the ground, are suddenly affected, and a great number of these latter animals have been found suffocated during the earthquakes in *Peru*.

† Von Humboldt, *ibid.* t. i. p. 484, and t. ii. p. 73. Von Hoff, *ibid.* t. xii. p. 567, t. xviii. p. 46. See also *Philos. Trans.* t. xlix. p. 415.

‡ Von Humboldt, *ibid.* Gehler's *Physikal. Wörterbuch*, new edit., t. iii. p. 804. Also during the earthquake of *Lisbon* (*Philos. Trans.* *ibid.*) and on the island of *Matschian* (*Hist. de la Conquête des Molluques*, t. iii. p. 318) the bursting forth of flames is reported to have taken place.

|| Von Humboldt mentions flames which rise from time to time out of two extensive caverns in the ravine of the *Cuchirano*. This phenomenon was accompanied, during the last great earthquake at *Cumana*, with a continued hollow subterranean noise. These flames are more especially to be seen during the rainy season.

it is going rather too far to take the explosion of fire-damp for the cause of earthquakes, as Kries does.* It is not impossible, that what has been taken for flames, if not altogether an illusion, was only an appearance of light, produced by the sudden expansion of highly compressed gases, exactly the same as is seen when an air-gun is discharged in the dark.

The heating and boiling up of the water in the sea and in lakes, the spouting up of streams of water, as well as the ejection of various substances from fissures in the earth,† which have occasionally been witnessed, may be satisfactorily ex-

* In his prize-essay on the causes of earthquakes.

† Von Hoff l. c. t. xxv. p. 73, t. xxix. p. 421. At the time of the earthquakes, which destroyed a part of *Italy* (1702-1703), many rents were formed in the *Abruzzi*, which emitted a large quantity of stones and then troubled water. The latter was thrown up higher than the trees in the neighbourhood. Flames and a thick smoke rose from the neighbouring hills, which continued three days with some interruptions. *Hist. de l'Acad. an. 1704*, p. 10. During the earthquake, the 21st October 1766, which totally destroyed the city of *Cumana*, the earth opened at several places in the province, and vomited sulphureous water. These eruptions were particularly numerous in a plain, which extends towards *Casanay* two geographical miles eastward of *Cariaco*, and which is known by the name of the hollow land (*tierra hueca*) because it seems to be every where undermined by hot springs. *Von Humboldt Reise*, t. i. p. 482. During the violent earthquake, which in one minute overthrew the city of *Caracas*, on the 26th March 1813, so much water was thrown up through the cracks, that a new stream was formed. At the same time the ground was also found covered with a fine white earth, like volcanic ashes, which had been thrown up from fissures in the neighbourhood. The eruptions of volcanic masses were still more considerable during the earthquake of *Riobamba*, 1797. The earth was fissured at innumerable places, and immense gulfs were formed in some places. Masses of water rose, filling up valleys 1000 ft. wide, and 600 ft. in depth; and also at the same time a peculiarly stinking mud, consisting of volcanic matter, accumulated so as to form considerable hills, now called *moya*. Wide rents were likewise opened during the violent earthquake in the north coasts of *South America*, last year, in order to give exit to streams of water which rose. It was often observed, that during the earthquakes, water with sand, mud, &c., was thrown up from wells, sometimes to a height of 30 ft. *Von Humboldt relates*, (*Relat. Hist.*, t. ii. p. 287) that this phenomenon is generally observed during the earthquakes at *Cumana*. The same thing happened the 1st Nov. 1755 near *Colares* (*Philos. Trans.* t. xlix. p. 416.), and also during the earthquake in *Calabria*. (*Journ. de Phys.* lxii. p. 263.)

plained by the rising of steam and gases, which may have the effect either of heating the water, or of throwing out solid bodies.* The same may be said of the concussions of the earth which takes place, sometimes in horizontal undulations, sometimes in vertical shocks, and sometimes with a vibratory motion, backwards and forwards. The latter of these convulsions, called by the Neapolitans, *moto vorticoso*, is most common during the greatest earthquakes.

Von Humboldt has proved, by abundant examples, that the propagation of earthquakes is not confined to any particular rock, but that the most varied formations are equally favourable to it. We infer, therefore, that the seat of earthquakes must be below all known rocks. Although all the rocks may be agitated, yet the manner of extension of the shocks in them is different, according to their particular quality. The earthquakes, which have at different periods ravaged *Smyrna*,† *Messina*,‡ *Kingstown* in *Jamaica* 1792, the county of *Pignerol* 1808,|| *Calabria*,§ *Talcahuano* in *Chili*,¶ &c. have always had a greater effect on diluvium and alluvium, than on rocks. Houses, for instance, built on sandy ground, were demolished, while those which stood on rocks were but little damaged. The shocks therefore act less violently and destructively on solid and rocky ground than on loose soil, which is unable to resist, and propagates the shock irregularly. In *Calabria*, where the loose soil occurred lying on granite on the declivity

* Thus, during the above-mentioned earthquake on the north coast of *S. America*, columns of smoke were seen rising out of the sea, a league from the shore, and in a depth of about 210 ft.; and in the night, flames were seen issuing from the same spot, which illuminated all the coasts of the island. After each shock, the sea retired, left the ships which were in the bay aground, and laid bare the rocks to a great depth; the waves at the same time ran to a height of 16 ft. to 20 ft. During the shocks the earth opened and closed again very rapidly. When tranquillity was restored, a whirlpool was observed in the sea, as if the waters were being swallowed up in an immense gulf. The temperature of the sea in the bay was raised, and bubbles of gas were seen rising all over the surface.

† *Hist. de l'Acad. des Sciences*, an. 1688. Buffon *Hist. Nat.* t. i. p. 515.

‡ Spallanzani, *Voyage*, t. iv. p. 138. || *Journ. de Phys.* t. lxxvii. p. 238.

§ *Oryktologische Bemerkungen über Calabrien &c.*, 1784.

¶ *Nautical Magazine*, Nos. 49 and 51, March and June 1836.

of the hills, the latter threw off the former, which glided down. Lastly, there are also instances of shocks extending irregularly in rocks.*

Many instances present themselves of earthquakes, which, in extending longitudinally, follow the direction of the rocks. This is the case, according to Palassou,† in the *Pyrenees*. Remarkable instances are presented in the phenomena of the 28th Dec. 1779; the 10th July 1784; the 8th July 1791; the 22d May 1814, &c. The regions situated more to the south, are, however, more affected than the chain itself.‡ Earthquakes in *South America* seem also to follow the direction of the mountains. Thus, that at *Caraccas* (1812) followed the direction of the littoral *Cordilleras* from E.N.E. to W.S.W.|| That of *Cumana* 1797, presented an instance of the same fact. The predominant direction of the frequent earthquakes on the coasts of *Chili* and *Peru*, is also that of the large chain of the *Andes*, which is parallel to the coast.§ All the older reports likewise state, that in these countries their direction is from S. to N., or *vice versa*; and Mrs Graham remarked, that she felt, during the violent earthquake in *Chili* 1822, as if the whole ground from north to south were suddenly raised, and then sunk again. Von Hoff¶ has also related the circumstance, that the shocks of earthquakes are most common in the same direction as that of the basaltic masses themselves, and around a certain distance on either side of the line in which they occur.

On the other hand, there are many instances of the countries of Europe having been agitated in all directions, without having been influenced by the mountains. Thus, earthquakes have extended from *Upper Italy* across the *Alps* to *Switzerland*. That at London (19th March 1750) followed the direction from W. to E., although the direction of the mountains in

* Berghaus' Almanack für das Jahr 1837, p. 72.

† Mém. pour servir à l'Hist. Nat. des Pyren., p. 260.

‡ Ibid. p. 916.

|| Von Humboldt, Rel. Hist. t. v.

§ That at *Cumana* followed the direction from N. to S., which is extremely singular, l. cit. t. iv. p. 16.

¶ Geschichte der Veränderungen der Erdoberfläche, t. ii.

England is from S.S.W. to N.N.E. &c. Sometimes the earthquakes originate from a common centre in a radiating direction on all sides. That of *Lisbon* (1755), that in *Calabria* (1783), and that at *Lima* (1746), &c. offer instances of this kind.

With regard to the earthquakes in *South America*, it has been observed that they occur principally in the mountainous countries. The cause which produces them, seems, as Boussingault* believes, to be so constantly in operation, that, if all the earthquakes, which are felt in the inhabited countries of *America*, could be noted, the earth would be found to quake nearly without intermission. These frequent movements of the ground of the *Andes*, and the slight coincidence between these convulsions and the volcanic eruptions, induce us to adopt the opinion of Boussingault, that the former are, for the most part, independent of the latter. He ascribes the greatest number of the earthquakes in the *Andes* to the sinking of rocks in the interior, which is a consequence of the former elevations of these chains of mountains. In favour of these suppositions, he affirms that these gigantic rocks have been thrown up, not in a doughy, but in a solid and fragmentary state, but that the consolidation of these fragments of crystalline rocks might not at first have been so firm, as not to admit of some sinking after the elevation. He refers to the Indian tradition which preserves the memory of the sinking of the celebrated mountain of *Capac-Urcu*, near *Riobamba*, the name of which signifies the chief, *i.e.* the highest, of all the mountains near the Equator. It is said that the top of this mountain has sunk in consequence of a subterranean shock which took place before the discovery of *America*. At the present time *Capac-Urcu* is lower than *Chimborazo*. Boussingault alludes to many instances, in which it is asserted, that the *Cordilleras* have sunk. Without taking into consideration the inferences drawn from barometrical measurements, made by Boussingault and his predecessors, which seem indeed to confirm that supposition, we will only mention the following circumstances. The French academicians, who, a century ago, were sent to *Quito* for the purpose of determining the form of the globe, were very much embar-

* Annal. de Chim. et de Phys., t. lviii. p. 83.

rassed in their station on *Guaguapichincha*, by the snow surrounding their signals. Now, for many years, no snow has been found on the summit of this mountain. The inhabitants of *Popayan* also have remarked, that the inferior limit of the snow covering the *Purace* is gradually rising, whilst the mean temperature has remained the same for the last thirty years, whence Boussingault infers that the *Purace* is sinking down.

That masses thrown up in a state of igneous fusion sink again by degrees, in consequence of their consolidation and contraction, cannot be doubted. But even if their elevation had taken place in a solid state, yet the immense masses of the *Andes* have risen from depths, where a pretty high temperature prevails. Supposing the *Andes* to have risen 24,000 feet in height, that part of them which is now at the level of the sea, must have been before the elevation so many thousand feet below it. This part brought, therefore, "with itself from beneath, a temperature which was $\frac{24000}{51} = 470^{\circ}$ F. higher than that which existed at the level of the sea before the elevation. The same holds good of each part of the *Andes*, in any depth, so that every where in erupted masses the temperature surpassed that of the adjacent rocks by 470° F. Whilst now these masses gradually lost their surplus of heat, they were contracted. But this cooling of these masses can, as far as they are within the earth, only be affected by conduction, therefore a long period will elapse for that purpose. That part of the *Andes*, which is elevated above the surface of the earth, and is exposed to the atmosphere, will of course cool a little more quickly. If the bases of the rocks thrown up be at a great depth below the surface, their contraction in consequence of their cooling may be very considerable, and as the elevation of the *Andes* is said to be one of the latest, this cooling and contraction may continue even at the present time in that part which is within the earth. It is therefore possible to conceive that these effects are the cause of the frequent earthquakes in the *Andes*.

Besides, there is nothing opposed to the hypothesis, that the powers, whatever they may be, which produced so remarkable a phenomenon as these elevations, may not even now operate in a less degree, and occasion the earthquakes so frequent in

the *Andes*. The later these elevations are supposed to have taken place, the more probable will such a hypothesis be.

If further proofs are still necessary to shew that the causes of earthquakes are only to be sought in the interior of the earth, we certainly find them in the fact, that these phenomena are totally independent of external circumstances. They take place whether the sky be clouded or serene, in hot as well as in cold weather,* before or after rain, sometimes with rain, and sometimes without it. Even the strength and direction of the wind seem to have no kind of connection with them.† Nor do they seem to be confined to any particular season of the year, although it is certainly remarkable, that of fifty-seven earthquakes which were felt at *Palermo* during a period of

* Many observers allude, indeed, to variations of temperature of the atmosphere before and after earthquakes; but, the academicians of *Turin* only have actually made observations on the temperature in the county of *Pignerol*. (*Journ. de Phys.* t. lxvii. p. 292.) They found that their thermometer always descended as soon as shocks had been felt. Thus they felt a vehement shock in the morning at half-past ten on the 10th of April, and their thermometer descended till noon from 26° to 22° . In fact it is to be desired, that farther observations should be made on other occasions, in order to confirm or refute the assertion of so remarkable a phenomenon.

† The late F. Hoffman in vain endeavoured to discover in the *Meteorological Journal* of the Observatory of *Palermo* (which included a series of years from 1792 to 1832, and where particular attention had been paid to the observation of earthquakes, of which no less than fifty-seven had there been accurately observed) some peculiarity of weather, which might, with any degree of plausibility, be supposed to have been connected with the earthquakes. The same result was obtained by Domenico Scinà in his memoir on the numerous earthquakes, which, in the years 1818 and 1819, caused so much apprehension in the neighbourhood of the *Madonian* hills.—Poggendorff's *Ann.* t. xxiv. p. 50 and 60. In contradiction to this are the traditions current in many countries. See among others, Berghaus' *Almanack*, 1837, p. 97, and following. There seems to be in fact some truth in the opinion, that earthquakes are most frequent and vehement at the beginning of rainy weather, and this phenomenon is even ascribed in *Jamaica* to a locking up of the pores in the crust of the earth by water, which impedes the rising of gases. On the other hand, cases have occurred in which earthquakes were preceded by a long-continued drought.—Barham in the *Philos. Trans.* t. xxx. p. 837, y. 1718, and t. xlix. p. 403; *Relat. Hist.* t. ii. pp. 273, 281, and t. v. p. 15 and 57; Hans Sloane's Letter with several accounts of the earthquake in Peru, Oct. 20. 1687, at Jamaica, 10th Feb. 1688, 7th June, 1692; *ibid.* y. 1694, p. 78; *Hist. des Trembl. de Terre*, t. ii. p. 442; *Collect. of the Massachusetts Hist. Soc.*, t. v. p. 223.

forty years, almost a fourth part happened in the month of March.* Perhaps the best means of ascertaining whether any connexion exists between earthquakes and meteorological phenomena, is the observation of the barometer. But Hoffman was unable to discover anything peculiar or extraordinary, either in the relative height of the barometer, in the direction of its motion, or in the extent of the oscillations, during the fifty-seven earthquakes above alluded to. The oscillations never went beyond their ordinary limits; indeed, in most cases they were very inconsiderable.† Von Humboldt also says that between the Tropics, on days when the earth is agitated by violent earthquakes, the regularity of the hourly variations of the barometer is not disturbed.‡

If aqueous vapours and compressed gases are the cause of earthquakes, there can be no doubt that hot springs and ex-

* Hoffman, loco cit. p. 52. It is also well known that in other countries, especially in *Chili* and the *Moluccas*, the periods of the equinox, for reasons of which we are ignorant, are considered as those most favourable to earthquakes. During the above-named period of forty years, this law does not seem to have been applicable to the autumnal equinox in that part of *Europe*.

† During the earthquakes the barometer stood decidedly oftener above the mean than under it. However, Hoffman remarks, p. 56, that during the only shock of importance which occurred in this period at *Palermo*, viz. in March 1823, the barometer remained the whole month constantly below the monthly mean.

‡ Reise, t. i. p. 487; also Relat. hist. t. iv. p. 19. Likewise Boussingault in Ann. de Chim. et de Phys. t. liii. p. 82. Other observations have also proved that the height of the barometer is totally unconnected with the cause of earthquakes, as for instance those of Don Felix Castillo Albo, during the earthquake in *Chili* in the year of 1822. See also Meyen in his "Reise um die Erde," t. i. p. 210. Those also made in the county of *Pignerol* in *Savoie* by the committee of the academy of *Turin*, during the earthquakes in the year 1808. The state of the barometer was also invariable, whilst the shocks at *Lisbon*, the 9th December 1755, were very strongly felt at *Turin*. Philos. Trans. t. xlix. The observations made on the island of *Meleda*, near the coast of *Dalmatia*, from the 15th November 1824 to the 28th February 1826, which likewise prove, that no connection exists between earthquakes and the pressure of the atmosphere, are very important, the shocks felt on this island having been the only ones of their kind as regards length of duration.—Die Detonations-Phänomene auf der Insel Meleda von P. Partsch, Wien, 1826, p. 204.

halations of steam and gases, may act as vents, and thus serve as a protection against them.*

Indeed, the ancients endeavoured to diminish the violence of subterranean explosions by means of wells and excavations. What Pliny,† the great Roman naturalist, says of the efficacy of these expedients, is repeated by the ignorant inhabitants of *Quito*, when they point out to the traveller the *Guaicos*, or clefts of the *Pichincha*.‡ But this is by no means confirmed by experience.

Farther reasons in support of the hypothesis which attributes volcanic phenomena to increased temperature of the interior.

However distinct natural philosophers may consider the causes of volcanic action, and those of hot springs, yet the close connexion of these two classes of phenomena refers us to one and the same cause. In proportion as satisfactory grounds can be adduced in support of any hypothesis, which explains one class of phenomena, so much the more probable does the hypothesis appear when applied to the other class. Though the seat of hot springs be concealed deep in the interior of the earth, and be as little accessible to immediate observation and investigation as volcanic action is; yet we may pursue and examine the phenomena of the former on the surface of the earth, and every point of time selected by the observer for this purpose proves equally favourable.

* Hoffman is inclined to ascribe the rarity and weakness of the earthquakes at *Sciacca* to the numerous exhalations of aqueous vapours, and to the great number of hot sulphureous springs, which occur in that neighbourhood, compared with other parts of *Sicily*, that are so often and so terribly visited by these destructive phenomena. *Poggendorff's Annal.* t. xxiv. p. 70.

† Lib. ii. c. 82 (ed. Par. 1723. t. i. p. 112.)

‡ Von Humboldt, *Reise*, t. i. p. 491. In *Peru*, the earthquakes are less frequent than in *Latacunga*, which is ascribed to the great number of deep hollows which intersect the ground in all directions in the neighbourhood of the town. Leonhard's *Taschenbuch*, 1822, p. 917. Von Hoff quotes many instances, in which several wells in *Rome*, *Naples*, and *Capua*, are said to have diminished or totally paralyzed the effects of earthquakes. But, in my opinion, an undue importance is ascribed to this effect of wells, for it is hardly to be conceived, that the effects of a cause, existing so deep in the interior of the earth, should be modified in any considerable degree, by an opening which penetrates the crust of the earth to so slight a depth.

Their wide distribution, the invariableness of their phenomena, the evolutions of gases from many of these, present to every attentive observer matter of investigation and consideration on their origin, duration, and connexion with other phenomena. If, then, we can succeed in proving that chemical processes can with much less probability be assigned as the cause of their being heated, that, on the other hand, the most convincing reasons shew that their heat is acquired at the expense of the interior of the earth : then will the hypothesis, which endeavours to explain volcanic phenomena from the same causes, gain no little increased weight. And in fact if hot springs be heated to such a degree as to attain the boiling point at a certain depth in the earth, we have but one step to make, by supposing this heat increased up to the fusing-point of volcanic stony masses, in order to attribute with equal probability, volcanic phenomena and hot springs to the central part of our earth.

I must observe, in the first place, as was formerly remarked, that, by thermal springs, I understand nothing more than springs whose average temperature exceeds that of the soil at the level at which they rise. It is therefore indifferent whether this excess consists in 1° or less, or in 50° or more. I can form no other idea of the meaning of the word thermal springs ; at least, I do not know what degree of temperature can be laid down as the boundary between cold and thermal springs, unless the distinction were to be perfectly arbitrary. Thermal springs (taken in this sense), are very widely distributed over the globe, as I think I have formerly shewn. Nay, I am convinced that, if we take any district of nearly equal height above the level of the sea, several of the springs will be found to exceed in average temperature that of the soil. An exception of this rule will certainly only be found in those situations where springs arise at the foot of hills more or less high, and which have acquired a cooler temperature from the higher regions.

If, like Professor Daubeny,* we regard chemical processes

* Report on the present state of our knowledge with respect to mineral and thermal waters. London, 1837.

going on in the earth as the cause of thermal springs, then must these processes be as universally distributed as the thermal springs. Those who entertain these views, however, do not surely contend, that these processes take place near to the surface, else how could we explain the fact, that, in boring Artesian wells, the greater the depth, from which the water rises, the higher is its temperature. As little explanation could be given of the circumstance, that springs rising in a small district near one another, often present no inconsiderable difference in their average temperature. In proof of the former assertion, I will cite out of many other instances that of the hole bored at *Rüdersdorf* near *Berlin*, where water at $74^{\circ}.3$ F. was drawn by boring to a depth of 880 feet; and in proof of the latter, the numerous springs in *Paderborn*, whose temperature varies from 49° to 61° F. In the former case, then, these presumed chemical processes must take place at least far below the depth of 880 feet; in the latter they must be supposed to be going on, either entirely below the situation of the springs at a nearly equal depth, or at various depths beneath each separate spring. In the previous case, their different temperatures would be occasioned by one spring running nearer, the other at a greater distance from, the common source of heat.

Daubeny speaks, in general terms only, of chemical processes; if we may, however, judge from a note,* he seems to allude to the same processes as those which he assumes as the cause of volcanic phenomena, viz. the oxidation of metals of alkalies and earths by water. We may pause a little to consider these hypothetical chemical processes, as they ought to inform us whence the agent, viz. heat, is derived, which is the point in question.

As the presence of thermal springs is so universal, these metals must be equally so. This hypothesis, especially in the extent given it by those who maintain it, viz. that the whole nucleus of the earth consists of an unoxidized mass, cannot be reconciled with the proportionate density of our earth, as I have already shewn. Yet, let us admit for a moment the existence of these metals in a more limited proportion. Their oxidation requires the access of water; we must, therefore, suppose as many chan-

* Report, &c., p. 68 and 69.

nels to conduct the water from the surface as there are thermal springs, or at least groups of thermal springs. Granting all this, the question yet remains to be answered, why the effects of these subterraneous oxidations are seen on the surface, in and near volcanos only; and why not even a trace of such processes can be detected in other places, which yet present innumerable thermal springs? Surely no one will bring forward the scanty evolutions of sulphuretted hydrogen gas from sulphurous waters as proofs of such processes. But, were the conditions necessary for volcanic activity fulfilled by the access of water to the interior in each of these channels, then would the occurrence of volcanic phenomena be much more frequent on our earth. Or, it must at least be assumed that they were at a former period as universally distributed as thermal springs now are; and that they have left behind a high temperature in the interior, which warms the springs, and, as Daubeny also assumes, extricates from the limestones, in the interior, the carbonic acid gas so universally present. That this is occasionally the case, namely that springs do acquire their heat at the expense of volcanic masses elevated at a distant period is certainly true, and has probably been of still more frequent occurrence in former times. I have myself already adduced instances of this kind. With the cooling of these masses, however, the thermal springs dependent on them must of course also cool, and whether this cooling take place in a longer or shorter time, must depend on the greater or less extent of those masses.

After the preceding remarks, the question remains, whether it be necessary to assume, in explanation of the universal distribution of thermal springs, a volcanic activity once so universally distributed; or whether their existence cannot be both more simply and more satisfactorily explained by an increased temperature in the interior, which is by no means merely hypothetical, but is supported by innumerable facts.

Daubeny says,* "They (the supporters of my views) should explain to us why primary rocks, traversed, as they so frequently are, with fissures of all descriptions, should not in every part of the world, and in every kind of situation, give rise to

* Report, p. 70.

hot springs, by evolving steam from their interior, and why they never appear to give issue to that class of thermal waters which I have noticed in *Ischia*, as being unaccompanied with gaseous products."

A spring arising from beneath leads us to conclude that meteoric water penetrates through clefts which communicate low down with the former. The experience gained in boring artesian wells shews that a succession of strata is most favourable for such processes, and from causes easily explained. In what are called primary rocks, however, no such alteration of strata is found, because they are not stratified. The usual occurrence, viz. the flowing of meteoric water down inclined surfaces of stratification which appear at elevated situations, and the rising of this water, by means of natural or artificial channels, after having been forced down to a more or less considerable depth, cannot then happen in unstratified rocks. It appears, nevertheless, that there are granitic rocks traversed by clefts more or less perpendicular, and communicating low down. Thus at *Aberdeen*, in *Scotland*, water has been drawn by boring in granite 180 feet below the surface, which, according to Robison, came from a cleft filled with sand and gravel, and rises six feet above the level of the earth.* Such a communication of the clefts low down, must, however, occur but rarely.

If the primary mountain rises above its environs and the clefts at its base lie exposed, then will the springs flow out of the clefts. Such an origin of springs, which are not naturally rising springs, is often observed at the foot of basaltic and trachytic cones, &c.

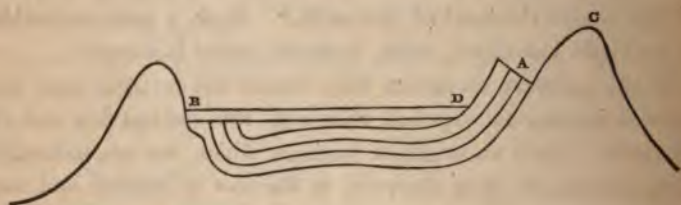
On the other hand, on the limits between stratified and unstratified rocks, where the latter have traversed the former, and where channels extending to a great depth have been formed in consequence of the contraction of the traversed masses during their cooling, circumstances favourable to these rising springs exist, and it is easy to conceive, therefore, that thermal springs may be found on the limits of these interrupted masses, but not in their interior.

Let us imagine a stratified chain of mountains consisting of

* Compt. Rend. 183 No. 24, p. 575, and t. ii, No. 20, p. 583.

several formations in a perfectly horizontal position, whose newest portion (jüngstes Glied) is much fissured, and under which an impervious stratum lies, then the meteoric water will penetrate the former fissured stratum, but be retained by the latter. As long as this horizontal position remains undisturbed, no rising springs can be supposed to exist in the whole of this district, and the inhabitants of such mountains could only supply their want of water by wells (Senkbrunnen). We will now suppose, that at two points of this district, volcanic masses are thrown up, and that, in consequence, a partial elevation of the strata takes place, as is shewn in the diagram, fig. 1. In this case, the hydrographic relations undergo considerable alterations. The consequence will be not only a movement of the water on the impervious stratum, in the direction of its inclination, but meteoric water will also penetrate at A between the older strata, where, during their undisturbed horizontal position, not a drop of water could penetrate, and this water will continue to flow in the direction of the inclination of the elevated strata.* At B, where these strata are also elevated, but

Fig. 1.



to a lower level, springs will commence rising; and as many of such springs may be supposed to exist in a district, as there are alternations of impervious and pervious strata in these mountains. The most copious springs, however, will be found between the mass that has been broken through and the oldest formation of the stratified mountain, because here, in consequence of the contraction of the former mass during its cooling, a cleft

* The same holds good with regard to the springs of fresh water. Thus on the *Schwäbisch Alp* springs are always found there where cones of basalt or basaltic tuffa have been elevated on the jura-formation. Plieninger in Poggendorff's *Annal.* t. xl. p. 493.

has been formed, which receives the meteoric water flowing down on that side of the elevated mountain C, which lies next to the raised strata. The meteoric water which flows down through the newest fissured stratum, will now as little give origin to rising springs as during its earlier horizontal position. If, now, after the period of this elevation, a stratum of a new formation should occur covering the extremities of the older raised strata, and extending from B to D, and if, lastly, the new formation contain impervious strata, then the conditions will undergo a change. The meteoric water, which penetrates at A, between each separate portion, will now all issue in the form of rising springs at B, between the elevated mountain and the new stratified formation which lies at its side. Should any obstacle here present itself to its exit, the water will even take a retrograde course B D, and issue at D, in which case the water between the last formed horizontal stratum and the impervious stratum lying under the newest raised ones will unite with it. We will not, however, enter into farther particulars, as many circumstances may be supposed to exist which modify the course of the springs; and still more complicated relations naturally arise when, after the deposition of the latest formed stratum, the elevation and raising are repeated. It will be sufficient to have called attention to the circumstance, that rising springs can only exist when the originally horizontal position of the stratified formations has been destroyed by elevations; and that the most copious springs and those which arise from the greatest depths are found precisely at the limits between the elevated masses and the raised strata.

Numerous instances can be cited in proof of this assertion. The *Pyrenees* and *Alps* present very characteristic circumstances. Thus Pallasou* shews, that not only are the majority of the hot springs in the *Pyrenees*, situated in the great granitic district at the eastern side, but also that all the others issue only from hollows of the newer formations, where the granite rises from beneath, at the foot of the declivities. He shews also, that even the degree of temperature of these springs depends on the greater or less exposure of their source; for the

* Mém. pour servir à l'Hist. Natur. des Pyrénées, 1815, p. 435, 459

thermal springs nearer the principal granitic mass are warmer while those more remote are colder.

Professor Forbes has likewise pointed out, in an interesting memoir on the temperatures and geological relations of certain hot springs, particularly those of the *Pyrenees*,* that, in the departments of the *Arriège* and the *Pyrénées Orientales*, where granite formations preponderate, in almost every case which he has examined, if springs rise in granite, *it is just at the boundary of that formation with a stratified rock*. In a great many cases it happens, that part of the springs rise from granite, and part from the slate or limestone in contact with it; and, he correctly observes, a more striking instance of the immediate connexion between thermal waters and disturbed strata could not be desired.†

According to the observations of several geologists, the tertiary rocks in the *Pyrenées* extend horizontally to the foot of this chain, without entering, as the chalk, into the composition of any part of its mass. Elie de Beaumont thence infers that the *Pyrenées* received their position, relatively to the neighbouring parts of the earth's surface, between the period of the deposition of green sand and that of chalk (a formation, whose raised strata, according to Dufrénoy's observations, ascend to the crest of this chain), and before the deposition of the tertiary strata of various ages.‡ We can very well explain, according to this supposition, why the springs in the *Pyrenées* issue between the elevated granite and the raised strata of slate and limestone. The circumstance above quoted from Pallasou, viz. that the temperature of springs becomes lower, in proportion to their distance from the principal granite-mass, may perhaps be of little importance, since, according to the remark of Forbes, cold sulphureous springs are to be found, even within not many yards of others, having a high temperature, and almost an identical mineral composition. Of this he has met with two

* Philos. Transact. for 1836, p. 575.

† At *St Sauveur* and *Thuez*, we have the co-ordinate, and, as Forbes p. 602, rightly thinks, connected phenomena of intrusive rocks, dislocations or fissures, metalliferous impregnation, and hot springs.

‡ See Poggendorff's *Annalen*, t. xxv. p. 26, also p. 58.

examples in very different parts of the chain, one at the *Eaux Baines*, where a perfectly cold spring rises within two hundred yards of the principal hot spring of the place, has similar medicinal properties, and is even more strongly impregnated with sulphur. The other example occurs at *Las Escaldas*, on the southern declivity of the *Eastern Pyrenées*, where a most efficacious cold sulphureous spring rises within about one hundred yards of a hot one. When, Forbes continues, to these facts we add others scarcely less curious, of springs of totally different mineral composition issuing from nearly the same spot, and with temperatures from 160° to 180° Fahr., as we see at *Ax* and at *Thuez*, we are forced to conclude that the source of mineralization must be independent, to a great extent, of that of high temperature, and that the arguments, as to the origin of thermal springs founded upon their chemical composition, must be to a certain degree fallacious.

The origin of the sulphureous waters in the Pyrenees can scarcely be sought for in the granite, since no substances are contained in it which can be supposed to produce such springs. If such springs are formed by the decomposition of sulphates by means of substances containing carbon, as is very probable,* then we must look for the origin of the *Pyrenean* sulphureous waters in the secondary formations, perhaps in some coal stratum, or even possibly in the tertiary formations. This inference holds, even if the sulphureous springs are formed in a manner opposite to this view. If, now, the origin of the springs in question, in other words, if the materials necessary for their formation be present in one of the newer parts of the secondary formations, then warm or cold sulphureous springs will result, according as warm or cold water penetrates to this point. The granite plays, then, no other part here, than that of rendering possible the descent of meteoric water to great depths, and its re-ascent in consequence of the raising of the

* See my memoir in the *Neues Jahrbuch der Chemie und Phys.* t. vi. p. 251, year 1832. The proportionally large quantity of organic matter in the *Pyrenean* sulphureous springs (among which that of Barépine, so called from the valley of *Bareges*, is remarkable) speaks but little in favour of their origin from mountain produced by volcanic fire.

strata effected by the granite, which circumstance causes the heating of these waters.

In this point, I think both theories agree; viz. that which attributes the heat of springs to chemical processes, and that which refers its origin to central heat: for those who hold the former opinion will doubtless not assign the stratified formations as the seat of these chemical actions, but the granite, or the parts beneath it. According to both theories, then, the meteoric water will become warmer in proportion as it approaches nearer to the source of heat, which can only be sought for at great depths.

As the subterraneous course of springs is subjected to many kinds of local impediments, so veins of springs of similar origin may flow out at points very remote one from another; and, *vice versa*, veins of very dissimilar local origin may issue very near one another. Nothing is therefore easier to conceive, than that any stratum in which the materials requisite for the formation of sulphureous springs are present, may be traversed by springs arising from very various depths, and therefore possessing very unequal temperatures, which circumstance would give rise to springs of similar chemical composition, but dissimilar temperature.

Forbes* remarks that the hot springs at *Baden-Baden*, on the border of the *Schwartzwald*, have a position almost identical with that which we have so invariably remarked in the *Pyrenees*. They occur just where the slate rocks have been violently upraised by a curious granitoidal porphyry, which forms the picturesque elevations near the *Alte Schloss*, and which passes into a true granite. Upon the slate, red sandstone lies unconformably. The elevation is among the older of M. Elie de Beaumont's systems: he expressly states that the *Grès bigarré* is undisturbed.

Relative to the thermal springs in the *Pennine Alps*, Bakewell† remarks, that, according to his observations, the exits of all of them lie partly in the primitive mountains of the central chain itself, partly, and indeed most frequently, at their extremities, at the boundary between the primitive mountains and the secondary formations.

* L. c., p. 609.

† Philos. Magazine, January 1828, p. 14.

According to the beautiful investigations of De Beaumont, two different systems are to be distinguished in the Alps, viz that of the Western Alps, and that of the principal chain from the *Valais to Austria*. *Mont Blanc* lies at the point of intersection of these two systems, which here meet at an angle of 45° – 50° ; also *Leuk*. The period of elevation of those two systems falls somewhat late. That of the strata belonging to the first system took place after the deposition of the newest tertiary formations of these regions, and that of the strata belonging to the second system between the deposition of the earlier diluvium (*des ältesten aufgeschwemmten Landes*) and the flowing of the diluvial streams, and at the time of the transport of the erratic Alpine rocks. The most favourable conditions for the origin of thermal springs evidently exist when the upraising, caused by the masses thrown up, extends to the newest formations. Therefore we are justified, under these circumstances, in expecting to find many thermal springs in this district, and especially at those points where two different systems of elevation have intersected each other at different periods, and admitted the meteoric water to penetrate to the interior. The thermal springs in the *Pennine Alps* are found partly in the direction of the principal chain of the *Alps*, partly, and more abundantly, in the points of intersection of this system with that of the Western *Alps*, and in this last system. Thus at Naters in the upper *Valais* (86° Fahr.); at *Leuk* (115° – 124°); in the valley of *Bagnes* at *Lavey*, south-east of *Bea* (113°); *Saute de Pucelle*, between *Moutiers* and *St Maurice*, in *Chamouni*; *St Gervaise* on *Mont Blanc* (94° – 98°); *Courmayeur* and *St Didier*, on the southern declivity of *Mont Blanc* (93°); *Aix les Bains* in *Savoy* (112° – 117°), with numerous hot springs in the neighbourhood; *Moutiers* in the *Tarentaise*, *Brida* in *Tarentaise*, and some at *Grenoble*.

It certainly deserves particular notice, that at one point of intersection (*Mont Blanc*) so many, and at the other (*Leuk*) the warmest springs are met with. Moreover, many thousand springs present themselves, some in the glacier streams, some under the glaciers themselves, and some may be stopped up. Thus, most of the above-mentioned thermal springs have been discovered only since Saussure's journeys; a few very lately, such as

that at *Lavey* in the bed of *Rhone* in 1831; and others again have become filled up.

Among those which occur in the continuation of the principal Alpine chain, I will mention only the two most celebrated, *Pfeffers* and *Gastein*. They are distinguished by their very small proportion of solid and volatile ingredients. In fact they are scarcely any thing more than warm glacier-water.* It seems to me that these thermal springs, and probably many others also in the *Alps*, resemble exactly those in *Ischia*, which *Daubeny* supposes to be purely the result of the infiltration of water to spots in the interior of the earth retaining a high temperature, with this difference only, that these spots lie somewhat deeper in the *Alps* than at *Ischia*, where the hot masses approach nearer to the surface in consequence of volcanic activity.

In regions where, after the earlier general elevations, later partial fractures and elevations have been produced by volcanic action, remarkable phenomena also present themselves, with regard to the existence of thermal springs; as, for instance, in *Auvergne*, and in the vicinity of the *Laacher See*.

In regard to the former, it is worthy of remark, that the baths of *Mont-Dore* are situated almost at the geographical centre of that group of hills, and also at the position of greatest dislocation; two of the centres of elevation, which *Elie de Beaumont* and *Dufrenoy* have pointed out, being found on one side, and one on the other. The springs issue immediately from trachyte, which is most remarkably and beautifully columnar just at the baths. These columns have an extremely slaty cleavage perpendicular to their axes.† Although the clay-slate rocks in the district of the *Laacher See* are very massive, and so far unfavourable to the penetration of meteoric water to great depths, yet the number of mineral springs here is very considerable. They belong, in general, to the class of thermal springs, although their temperature is for the most

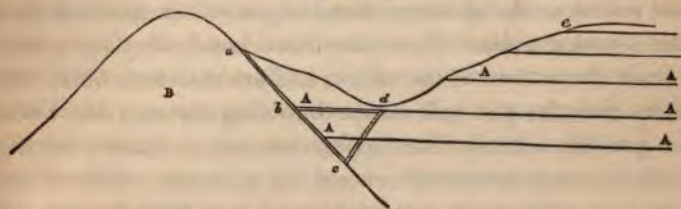
* Of the thermal water of *Gastein*, 10,000 parts contain only 3.5 solid matter; the same quantity of water from the *Lüttichine*, which flows immediately out under the glacier, contains only 1, and that from the *Aar* at *Bern* only, 2.2.

† *Forbes*, loco cit. p. 607.

part but little (often only $1^{\circ}.5$) above the mean of the soil. The strata of these rocks are raised, and thereby produce a descent of the meteoric water to deeper points; nevertheless, springs of this kind are very rare, where no volcanic masses have been broken through. In these rocks slate-surfaces (*Schieferungs Flächen*) are often found, which do not coincide with the direction of the strata, but intersect them at an acute angle. These slate-surfaces give origin here and there to mineral springs, and a copious disengagement of carbonic acid gas.

By far the greater number of the mineral springs there rise in valleys more or less deeply hollowed, on both sides of whose declivities, conical volcanic rocks, chiefly of a basaltic nature, have broken through. Some of them rise immediately from the clay-slate rocks, frequently from the cleavage surfaces which separate the strata of clay-slate and greywacke; and some come from volcanic masses (trass and volcanic ashes) which cover these rocks. The circumstance that these mineral springs seldom, perhaps never, flow out at the boundary between the erupted masses and the fundamental rocks, gives us an indication where to seek their origin. If the strata of the fundamental rocks A, A, Fig. 2, are inclined from the erupted volca-

Fig. 2.



nic mass B, then a cleft will be formed to a great depth in the interior of the earth at the boundary between this cone and the fundamental rocks, in consequence of the contraction of the former during its cooling. Down this cleft the meteoric water penetrates and meets the streams of carbonic acid gas developed in the interior. This latter is absorbed by the water, owing to the strong hydrostatic pressure exerted at so great a depth. This forms a water impregnated with carbonic acid, which effects a decomposition and solution of the stone, and hence

arises an acidulous spring, rich in carbonic acid and carbonates. The deeper the meteoric water penetrates, the warmer it becomes. Rising springs of water are then produced in this cleft, through which the concentrated mineral water formed beneath at *c*, rises to *b*. If here the direction of the slaty or stratified surface (Schieferungs oder Schichtungs Fläche) leads down to *d*, which either has an immediate exit in the section of the valley *a d e*, or runs at a slight depth below the surface, then the mineral spring will issue, owing to the pressure of the column of water *a b*. While the rising streams of warm water take the course *c b d*, the originally concentrated mineral water becomes diluted by the fresh water flowing down from above; the carbonic acid gas, absorbed in great quantity beneath, is gradually disengaged as the water rises, and consequently the hydrostatic pressure is diminished, and thus free carbonic acid gas is evolved at *d* with the acidulous spring. It is clear, that the carbonic acid gas, which is constantly disengaged from the rising water during its whole course, not only moves on with the water on the surface of the stratum *b d*, but fills all the intervals of the clefts in the whole clay-slate rocks, so that the gas will be evolved wherever these clefts are open at the surface. If these fissures open above the bottom of the valley, and therefore are not filled with water, at least not up to the opening, then the gas will escape from them with a hissing noise. If, on the other hand, they open from beneath the bottom of the valley, and are therefore filled with water, then the gas will escape bubbling through the water, and present entirely the appearance of a mineral spring. If, lastly, these fissures be covered by alluvium, which, nevertheless, does not form an air-tight covering, then the gas will escape silently from the ground, and such places are recognised from the scanty vegetation which exists there. I know but one of the first description of fissures in that district, which is found close to the first mineral spring called *Fehlenbor*, in the valley of *Burgbrohl*, between *Tönnisstein* and *Burgbrohl*. Such a fissure is found also in the *Eifel*, in the *Brudeldreis*, as it is called, not far from *Biresborn*. Fissures filled with water, from which gas is evolved, are tolerably numerous, as, for example, in the valley of *Burgbrohl*. I formerly considered these

spots (which are constantly met with in the vicinity of the brooks, and consist of little basins filled with water) to be actual mineral springs. If, however, the basin be emptied out, or the water drained off, it is at once perceived that no water springs up, but that merely an escape of gas takes place. I have had an opportunity of causing such gas-springs to be enclosed, and found the disengagement of carbonic acid gas to be extremely copious.* Fissures, covered by accumulated earth, are very frequently met with. If such a place presents a slight excavation, in which the gas collects, suffocated animals, as birds, mice, frogs, &c., are commonly found in it.

As springs run in the most different directions between the surfaces of strata, and through the fissures of the strata, so also do these disengaged gases. I have often had occasion to cause excavations to be made, in places where a scanty vegetation rendered the disengagement of carbonic acid gas at some depth probable. Fissures were often met with in the trass, out of which rose abundant streams of this gas. Sometimes natural canals in the trass were found under a covering of *Sphärosiderit*, which could be pursued from ten to twenty feet in a horizontal direction, or nearly so, and which doubtless were prolonged still farther.†

If the carbonic acid gas arises from below with considerable elasticity, and the cleft contracts very much from *b* to *c*, then it may easily happen that the meteoric water may penetrate but little below *b*. In this case, the column of water *a b*, will be as it were supported by the column of gas,‡ and at the point of contact, a constant absorption of the gas will be going on. In this manner, probably, are those mineral springs formed, which abound in carbonic acid gas, but contain very little solid matter, and whose average temperature exceeds but little that of the neighbouring wells. It must frequently be the case, moreover, that many springs which rise from a greater

* Jahrb. der Chemie et Phys. t. lvi. p. 129. (1829.)

† Neues Jahrbuch de Chem. et Phys. t. viii. p. 423, year 1833.

‡ The rising and falling of the periodic spring of the salt-work at *Kissingen*, is doubtless a consequence of the elasticity of carbonic acid gas. See Poggendorff's Ann. t. xl. p. 495.

depth, and therefore are originally warm, become cooled by mixture with cooler springs.

The warmest of the mineral springs in the environs of the *Laacher See* exceed the mean temperature of the ground by 7° to 10° Fahrenheit. What is worthy of remark is, that they rise from the deepest spots of the valley, where, therefore, their subterraneous channels are proportionably deepest under the rock, and possess already a relatively higher temperature. On pursuing the mineral springs up the valley, we find that their temperature decreases in a somewhat regular ratio.*

The proportionably small number of clefts in the clay-slate rocks may certainly account for the circumstance, that, in the *Laacher See*, the *Eifel*, and the *Taunus*, so few springs of considerable high temperature occur, though the channels of the carbonic acid gas lead down to such great depths, probably to points where a red heat exists. Such warm springs may perhaps owe their existence to the favourable circumstance of a cleavage surface, which intersects the strata at an obtuse angle, leading up from the cleft between the volcanic cone and the clay-slate rock, and opening at a valley, as *c d*. Perhaps the warm springs at *Bertrich* and *Ems*, which rise in deeply hollowed valleys in clay-slate rocks, are thus produced.

We may also easily conceive the possibility of obtaining a thermal spring by boring. A slight glance at the figure will shew that a hole bored into a clay-slate rock in a valley, in the vicinity of a volcanic cone, will probably give exit to a thermal spring, if the borer reach the surface of a stratum or a slate surface communicating with the cleft between the volcanic and the clay-slate rock. A successful attempt of this kind was actually made a few years ago, by boring into the clay-slate rock at the foot of the basaltic hill, the *Landskrone* in the *Ahr* valley, about three German miles north of the *Laacher See*, when a copious mineral was obtained of the temperature of 58° F., affording considerable disengagement of carbonic acid gas. Indications prognosticating a favourable result of this undertaking were indeed present, inasmuch as a mineral spring

* So in the chain of *Taunus* mountains, the warm springs rise deep in the valley, the cold acidulous springs on the heights.

already existed at the distance of but a few steps from the spot.*

Phenomena, perfectly resembling those which are observed where volcanic masses have actually broken through, present themselves very frequently. A cleavage, reaching to great depths, may also be a consequence of a preceding elevation and fracture of the component strata, without an actual breaking through having taken place. These phenomena are found in formations of all ages. Thus Hoffmann† has pointed out, in the north-west of *Germany*, some peculiar valleys which, originally perfectly closed, are surrounded on all sides by a precipitous escarpment, whose component strata incline from the centre downwards in every direction. He has given to these valleys the name of valleys of elevation. The most remarkable of these, are those of *Pyrmont*, *Meinberg*, and *Driburg*, where the well-known chalybeate springs rise, accompanied by a considerable disengagement of carbonic acid gas. *Pyrmont* and *Meinberg* lie precisely at those places where the directions of the north-eastern system of mountains and of that of the *Rhine* intersect.

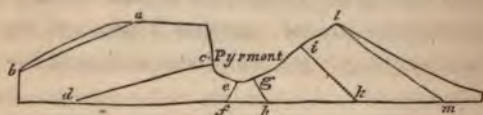
Here, therefore, we find also a considerable disengagement of carbonic acid gas; yet no volcanic masses which have broken through; but only the secondary strata of shell limestone, of keuper and variegated sandstone, raised up and fractured. The mineral springs are of another kind, and the alkaline carbonates are wanting, while sulphates and metallic chlorides

* A joint-stock company is also at this moment employed in boring into clay-slate rock at *Thal-Ehrenbreitstein*, near *Coblentz*, in order to procure thermal springs. Since this spot lies scarcely two German miles distant from the well-known hot springs of the temperature of 75° to 131° F. at *Ems*, and at a lower level, and since an acidulous spring already exists there, the possibility of the success of this undertaking is as little to be despaired of, as a favourable result can be promised. Leop. von Buch's remarks on this subject in *Nöggeraths Ausflug nach Böhmen*. Bonn. 1838, p. 5. The instance of the salt work of *Nauenheim*, near *Friedberg*, where a salt-spring of 100° F. with immense disengagement of carbonic acid gas was obtained by boring, proves that success is more likely to attend by boring into secondary formations, where a more frequent alternation of various strata exists. At *Hofgeismar*, near *Cassel*, a new thermal spring with copious disengagement of carbonic acid gas was also obtained by boring in May 1834.

† Poggendorff's *Ann.* t. xvii. p. 151.

supply their place. We may easily explain this by the absence of rocks containing alkalis; for instance, basalt or any other volcanic rocks. The clefts produced by these fractures reach certainly to great depths; carbonic acid gas may be evolved from them, but its elasticity seems to prevent the penetration of meteoric water. The mean temperature of the mineral springs there, exceeds, therefore, but little that of the place of their occurrence. This is especially the case with the mineral springs at *Meinberg*, whose considerable annual variations of temperature prove that they take their origin very near the surface. The considerable elasticity with which the carbonic acid gas escapes, and which is greater than I have observed at any place where gas is evolved, prevents, no doubt, the deep penetration of meteoric water. Moreover, we may remark, that the inclination of the strata, from the centre downwards in every direction, carries the meteoric water away from the seat of the evolution of the carbonic acid gas. Even supposing, then, that the water could penetrate to the depth of the channels of carbonic acid, it would not rise, owing to the absence of the pressure of a column of water. The section of the valley of elevation of *Pyrmont*, taken from Hoffmann's work, Fig. 3. distinctly shews the inclination of the strata *a b*,

Fig. 3.



c d, e f, g h, i k, l m, from the centre downwards.

It is possible that the raising and fracture of the secondary strata in such valleys of elevation, was the consequence of the elevation of volcanic masses from beneath, which masses have not appeared at the surface. Supposing this to be the case, we can easily imagine that at such places mineral springs may be produced which contain carbonates of alkalis, because the meteoric water only can penetrate to these masses. But the low temperature of the acidulous springs in question, shews that meteoric water penetrates to very small depths only at these places.

Valleys of elevation of the kind described seem to be of tolerably frequent occurrence; thermal springs and disengagements of carbonic acid gas are not, however, always met with, either for want of sufficient depth of the clefts, or for want of materials which give rise to the disengagement of carbonic acid gas. Instances of three of such valleys at the eastern end of the basin of *London*, are given by Buckland.* See also his and Conybeare's† description of the structure of the country at *St Vincent's* rocks; and the example at *Matlock* long ago pointed out by Whitehurst.‡ Many other instances of this kind occur in Daubeny's report.|| Stiff§ also has long ago shewn, that the rocks in the neighbourhood of the mineral springs of the *Nassau* territory manifest evident changes in the direction and inclination of their strata, especially saddle-shaped elevations, often accompanied with fractures.

Finally, dislocations or faults produced by elevations and intersecting stratified rocks, may direct the subterranean course of springs in a very different manner. Buckland¶ has given many instances of springs originating from causes of this kind.

If we take a summary view of all that has been said on the subject of thermal springs, we shall find it impossible to avoid recognising a relation between elevations of Plutonic masses, the upraising of Neptunian formations, and thermal springs. Cause and effect have, however, been frequently confounded here. Thermal and mineral springs are seldom, perhaps never, the cause of those effects. Where, however, these effects are observed, where, in consequence, the penetration of meteoric water into the interior of our earth has been rendered possible, and where natural hydraulic tubes have been formed by the upraising of strata, there the phenomena of thermal and mineral springs were the consequence.

We should transgress our limits, were we here to pursue the subject of thermal springs in their chemical relations, since the

* Geological Transact. sec. ser. vol. ii. part i. p. 119.

† Ibid. vol. i.

‡ Theory of the Earth, 1786.

|| P. 66.

§ Rullmann Wiesbaden, &c. 1823, p. 103.

¶ Geology and Mineralogy, &c. London 1836. Vol. ii. p. 106 and 110.

general aim of these remarks is to shew that their degree of heat depends on the greater or less depth of their origin, consequently wholly and solely on central heat. The following remarks, however, upon their chemical constitution, may perhaps not be entirely superfluous.

The chemical ingredients of those springs which take their origin at the boundary between volcanic and Neptunian formations, are derived in some springs from the former, in others from the latter formations, in others again from both. The following conjecture is probable. If considerable quantities of carbonate acid gas are disengaged from the interior, which are absorbed under strong hydrostatic pressure by the water, and thus act on the volcanic stone, decompositions ensue. The alkalies which are found in all stony masses of igneous origin, are extracted by the carbonic acid, and taken up by the water as carbonate of alkalies, and especially carbonate of soda. In the same manner are formed the bicarbonates of lime, magnesia, and of protoxide of iron. Metallic chlorides and sulphates may perhaps be less frequently derived from volcanic matter, and more so from the Neptunian formations. In this manner probably are formed the great number of springs, which rise in the neighbourhood of basaltic hills. Where there is no disengagement of carbonic acid gas from the interior, no such mineral springs are found; at least we cannot assume that in this case the volcanic rock contributes any thing essential to the constituents of the springs. Thus, probably, neither in the *Pyrenees* nor *Alps* do the springs take up any thing essential from these rocks. The circumstance, that springs of very various chemical composition arise in the vicinity of the granite of different mountains, might here serve as an indirect proof. At the same time, the nearly similar composition of the springs occurring in the neighbourhood of the basalt cones, where carbonic acid gas is disengaged, however different may be the Neptunian formations, is an argument in favour of these springs deriving their ingredients principally from the basalt.

The organic matter found in such abundance in the sulphureous springs of the *Pyrenees* (baregine, glairine, animal matter) proves, that their chemical constituents must be derived at least in part, from the Neptunian formations. Since no carbo

nic acid escapes from the rocks there, the granite in the interior may, indeed, suffer but slight decompositions. The formation of the sulphureous springs there, probably by the decomposition of sulphates by organic matter, is certainly much favoured by the high temperature of these springs; and this again is a consequence of the great depth, to which the clefts extend in the strata, which are piled up one on another in considerable masses, and partly raised up, with many strata-surfaces between them. The coincidence of various circumstances may thus produce one class of thermal springs in preference to another.

In the *Alps*, where, on account of the absence of escapes of carbonic acid gas, decomposition of the granite and other volcanic rocks does not take place, and where even the Neptunian formations contain few soluble substances, we find thermal springs, which are scarcely any thing more than ordinary warm water.

On the other hand, we see thermal springs issuing, to all appearance, from erupted masses, which springs contain ingredients apparently peculiar to those which can be proved to issue from Neptunian formations. This is, for instance, the case with the salt-spring, which rises at *Kreuznach* out of porphyry. This rock is but little fissured, and yet the high temperature of the springs, 58° to 83° , indicates a deep origin. Since the porphyry has penetrated the variegated sandstone, the latter, and also the shelly limestone, lie in close contact with the springs, so that this volcanic rock has no other share in the formation of these springs, than the production of deep clefts between itself and the Neptunian formations, which have permitted meteoric water to penetrate into the strata containing the salts. We must not pass over one circumstance, which induces us to attribute to these saline springs a totally distinct origin, viz., that sulphate of lime, which otherwise so generally accompanies the common salt, is here entirely absent, and that these springs are remarkable for their abundance of bromine and iodine.

As escapes of steam (fumaroles) shew themselves in regions (Tuscany for example) where hot masses have approached the face of the earth by volcanic activity, one might perhaps be induced to expect evolutions of steam from clefts penetrating

deep into the interior. It must, however, be observed, that between these two cases a wide difference exists. In regions where volcanic action still manifests itself, clefts can with ease extend in masses which are of a boiling heat or even hotter. Meteoric water penetrating these clefts will be converted into vapour and exhaled. Were, however, such a phenomenon to shew itself in regions where the increase of temperature follows the progression, which we have found it to do in accessible depths, then must such clefts extend perpendicularly to a depth of about 8280 feet in our country. But are any rocks, even the unstratified masses, traversed by continuous clefts of so great a depth? In granite the prismatic separation is very frequent. The columnar structure is most distinct in basalt, aphanite, and all dense and homogeneous rocks. The columns are sometimes traversed and disjointed by traverse clefts. The surfaces of separation (*Absonderungs Flächen*) in the smaller masses, always lie perpendicularly on the adjacent ones, as do also the columns, when present. Let us assume that such a jointed separation extends to the requisite depth, and that meteoric water penetrates so far, and then it will certainly rise converted into steam; when, however, it attains the higher colder regions, it will become condensed again, and resume the same course or circulation.

Since the volcanic masses, when thrown up, form, generally, the greatest heights, we must look in them for the compressing columns of water, which render the rising of the springs possible. The possibility of such a case is conceivable, when the surface of the unstratified rock is inclined in one or more directions, and the columnar separations are jointed by transverse clefts. It is, however, even then, possible only when the transverse clefts have no continuation outwards, for in this case the water will take a side course, and either issue on the slope of the rocks as springs, or, if raised strata exist, it will take the course designated in the preceding remarks. These two last cases seem to be the most usual, as the circumstances above explained prove, viz., that thermal springs most frequently present themselves between the unstratified and stratified rocks. I have imagined the last case, in order to exhibit the possibility of hot springs rising in the *Alps*, when water descends from

great heights to the interior of the rocks, flows through warmer strata of earth, and then makes its exit in the valleys. It is clear that such springs merely flow from above downwards, when the raised strata make their appearance externally, but that they will, on the other hand, rise again, if the strata are upraised in the form of a trough on the opposite side.

Phenomena lately observed, may perhaps present cases, where the effect of the internal heat of the earth nearly approaches the surface. Marcel de Serres,* for instance, describes a cave near *Montpellier*, situated in the Jura limestone, in which, at depths of 135 and 150 feet, a constant temperature of $72^{\circ}.5$ F. prevails, which exceeds by 10° the mean temperature of *Montpellier* ($62^{\circ}.5$). He shews that no accidental circumstance, such as decompositions, the burning of tapers, or the respiration of those who visit this cave, can be the cause of this phenomenon; but believes it is to be sought for in the central heat, which rises through clefts and affects one point more, another adjacent one less. Thus, at the distance of about 1200 feet from this cave is found a cleft in the same formation, from which issue watery vapours, whose temperature, $73^{\circ}.5$ (that of the external air being 52° – $54^{\circ}.5$), is nearly the same as of an artesian well close in the vicinity of the cave (70° – 72°). These vapours, which probably rise from thermal springs existing beneath, are constantly disengaged, and maintain a temperature of $73^{\circ}.5$, though in constant contact with the external air. The cleft from which they issue, communicates with other wider clefts, which expand into caves, into which the inhabitants of the estate of *Astier* have already penetrated. The labourers on this estate are in the habit of warming themselves pretty frequently in the hole where these vapours are formed. On examination, this vapour has all the purity of distilled water. At an earlier period there existed, at the distance of 150 to 180 feet N.E. of the grotto of *Astier*, another opening from which an equally warm vapour was evolved, which could be perceived at some distance off. This opening has, however,

* Des Cavernes chaudes des environs de Montpellier in *Annal. de Chim. et de Phys.* t. lxxv. p. 280.

been since filled up. This constant vaporization of water, in the middle of the same rock in which the cave is found, shews pretty evidently the cause of the warmth in the latter.

It is scarcely to be doubted, but that, on closer investigation, the phenomenon of local heat in caves in the limestone rocks, which are fissured to such great depths, would be found to be of more frequent occurrence. The spring of the *Orbe* in the Jura mountain, formerly mentioned, which is nothing more than the discharge of the lakes situated 680 feet higher in the valley of the *Joux*, proves, among others, to what a depth the clefts in the limestone rocks descend.

The whole ridge of the chalk hills of the *Teutoburger Wald* near *Paderborn*, is fissured to depths exceeding 800 feet, so that, on this whole ridge, either no springs at all, or but a few very scanty ones, are met with, which probably owe their existence to partial beds of marl in the chalk rocks. In three villages which lie on this ridge, there is but one well 80 feet deep. On account of this almost total want of water, these are called the "Dry Villages." The cleavage continues in the valleys which traverse these hills, consequently the brooks and rivers which flow through them gradually sink and flow out of the openings of these valleys only in the wet season of the year. At the foot of these chalk hills on the other hand, where the fissured limestone is covered by a stratum of marl, a very great number of copious springs issue, several of which form considerable rivers, as the *Lippe*, *Pader*, *Heder*, &c., immediately after their exit. The cleavage of the chalk rocks is doubtless continued in the *Quader Sandstein*, which lies below and probably is limited by the *lias* (*gryphitenkalk*) and variegated marl, which follow immediately below the green sand, and which are remarkable for their large strata of clay marl (*thonmergel*), that are impermeable, unless broken or dislocated by elevations. This whole chain of hills, then, from the clay-marl strata to the level of the springs which issue on the western declivity of the *Teutoburger Wald*, is, therefore, saturated with water like a sponge. Not merely geognostical reasons, but also physical relations, furnish incontestible proofs of the existence of these considerable subterraneous reservoirs of

water. For instance, while the water of the above-mentioned sinking brooks and rivers penetrates into the interior of the hills with the variable temperature of the seasons, the waters of the numerous springs of *Paderborn*, whose mean temperature is 50°.6 F, and exceeds the mean temperature of the soil by about 1°.7, present already a uniform degree of heat. Thus, on the 21st May 1834, I found the temperature of the *Alme* at *Brenken*, where considerable masses of the water of this river flow down through the clefts of the chalk, to be 63°, while the springs at *Geseke*, at the distance of 22,000 feet, which doubtless receive their supply from this river, were of the temperature of 49° to 51°. The miller there, whose mill is turned by one of these springs (what is called the *Völmeder* spring), told me he had often opened the holes found on the banks of the *Alme*, and let in as much water as would have been alone sufficient to turn his mill, but that he never perceived the slightest increase of the streams. This also proves the great extent of the subterraneous reservoir of water, whose discharges are not perceptibly increased by an addition of water. If, indeed, these additions are continued by continued wet weather, and the level of the subterraneous reservoir rises, then, not only will those springs become more copious, but water will also issue from high-situated channels, which contained no water during the dry season. Lastly, the same miller assured me that the muddiness of his mill-streams by no means depended on that of the *Alme*, since they always become so after rain. Opinions were, however, divided on this point, as other inhabitants of *Geseke* maintained, that, within twelve or sixteen hours after rain, the *Alme* became muddy, and the *Völmeder* springs became so too, while this had no influence on the springs in the town. Be this as it will, thus much is certain, that all the springs there do not become muddy after rain, but that many always remain clear, as the warmer among the *Pader* springs. This circumstance is also a satisfactory proof of the great extent of the subterraneous reservoir, because, notwithstanding the fact, that the sinking rivers and brooks, as well as the rain-water and snow-water, which penetrate into the fissures of the fissured rock, are all muddy in rainy weather, yet the warmer

springs, those consequently which rise from a greater depth, run out clear.

I have instituted some experiments in order to ascertain what must be the extent of a single mass of water, which retains a uniform temperature, when a given quantity of water is added to it, whose temperature varies with the variable temperature of the rivers of our latitude, and when from it is discharged an equal quantity of water, whose annual variations of temperature are limited to those observed in the coldest of the *Pader* springs.* The water-district (*Wassergebiet*) of these springs is about 216 millions of square feet, and the quantity of water which they afford in one minute 16,530 cubic feet, according to measurements, as accurate as the nature of the thing would admit. It was calculated, from these numerical data, that a mass of water, 120 feet in depth, must be present in this district where the springs rise, if all the water which sinks here in half a year produce an alteration of temperature of $2^{\circ}.25$ F., presupposing that a mean difference of $22^{\circ}.5$ exists between the temperature of the water which sinks, and of that which lies in the fissured rock. Since, however, the presupposition that *all* the springs in *Paderborn* undergo this variation of temperature of $2^{\circ}.25$ in a half year, applies only to those whose average temperature does not exceed $50^{\circ}.6$ F.; while the warmer springs, which are by far the more numerous, exhibit no variation of temperature during the whole year; the size of the subterraneous reservoir must be much vaster, if such *considerable* quantities of water of a *uniform* temperature flow from it, while the water, which sinks and is added to it, suffers variations of temperature dependent on those of the atmosphere.

* It is really a remarkable fact to see so considerable a number of springs rise in so small a compass as the lower part of the town of *Paderborn*. Their number is said to amount to 130, several of which constantly appear close together, often at the distance of but one or two paces, and immediately form considerable brooks, which by their union form the *Pader*, so large a river, that its different branches turn no less than fourteen undershot water-wheels of the town situated near together. Almost equally large masses of water, however, derive their sources from *Lippspring*, *Kirchbornchen*, and *Upsprung*, not to mention the many other springs which lie dispersed at the foot of that chain of hills.

Calculations of this kind can, from the nature of the subject, give but approximations to the real size of that of which we could otherwise form no estimate at all. The preceding calculation shews, at least, that all the clefts and caverns in the chalk rock of the *Teutoburger Wald* must be filled with water from the level of the springs, down to some impermeable stratum. How otherwise can we explain the fact, that considerable quantities of water of the varying temperature of the atmosphere constantly sink into the rock, and that as considerable quantities flow out at the slope of the rock, presenting a uniform temperature, or at all events one which varies only $4^{\circ}.5$ Fahr. in a whole year. Since the conjecture is probable that the lias and the variegated marl present the first entirely impermeable strata, we may also conclude, that not only the chalk formation, but also the green sand, which is equally fissured, are filled by the reservoir, and that its bottom is formed by the above-mentioned impermeable strata. Lastly, the high temperature of what are called the warm Pader springs ($54^{\circ}.5$ — $61^{\circ}.25$ Fahr.) indicates also an origin from a greater depth, if they do not flow in distinct channels, but come from warm streams, which rise from the base of the reservoir.

The copious springs, which rise on the western declivity of the *Teutoburger Wald*, owe their abundance of water, even in dry seasons, to these vast subterraneous reservoirs; and what is derived from these reservoirs, is abundantly replaced in the rainy seasons, when nearly all the water collected in a district so much fissured, penetrates into the interior.

These large masses of water, whose temperature exceeds, by several degrees, the average one of the district under which they are collected, and which bring so much the more heat to their surface the deeper they penetrate, have doubtless the effect of warming the hills under which they exist. It is therefore perhaps a phenomenon of universal occurrence that all chalk hills, which are much fissured, and into which brooks, rivers, and most of the meteoric water sink, maintain a relatively higher temperature. The Pader springs alone, however, shew how inexhaustible must be the sources which warm such vast masses of water. These springs furnish in a year at least 8688 millions of cubic feet of water, whose average temperature exceeds

by at least $6^{\circ}.75$ Fahr. the average temperature of the ground at *Paderborn*, and this excess would melt a cube of ice, having a side of 984 feet. This heat is irrevocably withdrawn from the interior, and yet the thermal springs of *Paderborn* have sustained no diminution of heat from time immemorial.* Chemical processes, which could there give rise to such inexhaustible sources of heat in the youngest secondary formations, must be, or have been, carried on to a great extent indeed !

* By far the greater number of the remaining copious springs, which rise on the western declivity of the *Teutoburger Wald*, are also thermal ones. Some, for instance, in *Lippepring* attain a temperature of $54^{\circ}.5$.

APPENDIX.

ADDITIONAL REASONS

AGAINST THE

CHEMICAL THEORY OF VOLCANOS.

1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22
23
24
25
26
27
28
29
30
31
32
33
34
35
36
37
38
39
40
41
42
43
44
45
46
47
48
49
50
51
52
53
54
55
56
57
58
59
60
61
62
63
64
65
66
67
68
69
70
71
72
73
74
75
76
77
78
79
80
81
82
83
84
85
86
87
88
89
90
91
92
93
94
95
96
97
98
99
100

ADDITIONAL REASONS
AGAINST THE
CHEMICAL THEORY OF VOLCANOS.

Professor Daubeny* has replied to my objections to the chemical theory of volcanos, with that fairness which might be expected from a scientific man, who only looks to the topic of the discussion, not to the opponent. Venturing to continue the discussion on this subject a little farther, I by no means wish to forget the merits of a naturalist, who has distinguished himself so much by his description of active and extinct volcanos, and by a variety of valuable memoirs on similar subjects. I feel happy to meet with such a man in the very same field of science, and I hope that the differences in our opinions will become less considerable, the more they are explained.

The chief question is, whether the internal heat of our globe is sufficient to account for volcanic phenomena? or, whether the supposition of intense chemical actions explains them in a more satisfactory manner? As for the internal heat of the earth, I am of opinion that it may not be considered as an hypothesis, but as a fact well grounded on numerous phenomena. Granting this, it must be imagined that the rocks of the earth are, at a certain depth, in a liquid ignited state. Indeed, it is well known that, by volcanic action, melted masses (lava) arise from the interior, and that, on slowly cooling, they produce rocks such as basalt, trachyte, &c., forming a considerable part of the external crust of the surface of the earth. The chief explanation of volcanic phenomena depends, therefore, according to the theory alluded to, upon demonstrating the means which nature makes use of to bring such melted masses to the surface of the earth. In my

* Jameson's Philosophical Journal, vol. xxvi. p. 291.

former publications in this Journal concerning the natural history of volcanos and earthquakes, I flatter myself that I have shewn, as far as it is possible to elucidate a subject which is beyond the limits of direct observation, and which can for the most part only be mentally appreciated, that watery vapours may be supposed to be the means by which nature is able to carry melted masses from the greatest depths to the surface of the earth. Any hypothesis endeavouring to explain the volcanic action, must embrace watery vapours or other elastic fluids, in order to account for the rising up of lava. The theory in question, consequently, reduces the explanation of the phenomena presented to the most simple point.

Let us now consider, somewhat minutely, the theory which ascribes volcanic actions to chemical processes taking place between bodies having a powerful affinity for each other, and by which so considerable a heat is produced as to melt lava. First, the advocates of this hypothesis must be asked, whether they are inclined to deny a high internal heat of the globe increasing with the depth to the point of melted lava, or whether they suppose chemical changes supported by this intense temperature? Admitting for an instant the former case, all the heat required to melt lavas must be produced by these actions. Professor Daubeny seems to be inclined to suppose this; for, to my objections that these metals are not sufficiently oxidizable to kindle on the access of water, he replies, that silicon is combustible when united either with a little hydrogen or with alkaline carbonates, and that calcium and magnesium appear to be still more inflammable. The Professor seems, therefore, not to consider the internal heat as a co-operative power, but to think it possible that the metals, even at a common temperature, generate heat enough, by combining with oxygen, to melt the produced earths.

It is scarcely possible to confirm or to refute this assertion in an experimental way. Indeed, the combustion of a mixture of the earthy and alkaline metals, in such proportions as are contained in lava, would give a satisfactory conclusion only by applying these metals in such large quantities, that the heat absorbed by surrounding bodies should be insignificant in proportion to that which is generated. Supposing, on the

other hand, that the advocates of the hypothesis presented, allow the existence of a central heat supporting chemical actions, it would not be difficult to conceive the melting of lavas.

I shall not pass from this subject without adding, that this hypothesis does not necessarily require the volcanic actions at very considerable depths below the surface of the earth, but merely where the earthy and alkaline metals were present. This circumstance may perhaps be viewed as more favourable to the hypothesis in question than to the other, which assumes a central heat, and consequently considerable depths, for volcanic actions. But are there grounds for supposing that the place where these actions are developed is near the surface of the earth? On the contrary, all volcanic phenomena, both the eruptions themselves and earthquakes, afford decided proofs that volcanic actions are peculiar to a spot very deep below the surface. As to this subject I refer to my former publications.

The theory of Professor Daubeny supposes the existence, near and about the focus of a volcano, of vast caverns, caused originally by the heaving up of the softened rocks, owing to the elastic vapours disengaged, and consequently filled in the first instance by these matters. Granting the passages between these caverns and the external atmosphere not to be hermetically sealed during the state of rest of the volcano, air must enter into them. But it is obvious that, on the beginning of the volcanic action, particularly on the heaving up of the lava, those passages must be completely interrupted; therefore, only that air which formerly entered the cavities can act on the earthy and alkaline metals supposed to be in their vacuity. This effect will consequently be limited, and finished as soon as the oxygen of this air is consumed. In order to gain a distinct notion of the quantity of air requisite to produce a certain quantity of lava by oxidation of the earthy and alkaline metals, let us make the following calculation: Let us take, like Professor Daubeny, for instance, the analysis of the lava from *Etna* given by Dr Kennedy. According to the calculation given by the former, 58 parts of the metallic bases of this lava require 42 parts of oxygen to give 100 parts

of lava. 100 parts of atmospheric air, containing 23.32 parts of oxygen by weight, 100 parts of lava will require 180 parts of air by weight to be produced. Lava being 3.2 times heavier than water, and water being 770 times heavier than atmospheric air, lava is consequently 2464 times heavier than the latter. Therefore, the production of 1 volume of lava will require 4435 volumes of air. In my former papers, I have mentioned that the violent eruption in the low country of *Skaptar Jokul* in *Iceland*, in 1783, brought up a mass of lava so considerable as to surpass in magnitude the bulk of *Mont Blanc*. According to that calculation, such a mass, if constituted like the lava examined by Dr Kennedy, would have required a quantity of atmospheric air equal to the bulk of 4435 times the size of *Mont Blanc*, had that lava been generated by oxidation of the metals contained in it. Thus a bulk of nitrogen gas of 3503 times as great as that of the mountain mentioned, must have been evolved during the formation of that mass of lava.

It is beyond all probability to suppose caverns of such an enormous extent in the interior of the earth for containing such huge quantities of atmospheric air. Therefore, the advocates of the chemical theory will be obliged to assume very long periods for the formation of such masses of lava, during which the passages between the internal caverns and the external atmosphere must have been always open. Thus, they must suppose that atmospheric air must enter these caverns and quit them, after having been deprived of its oxygen, and that this entrance and exit of air took place unceasingly during the whole time of these actions. But it is obvious that these streams of air must be supposed to exist in such proportions as to support these actions, as soon as melted masses require to be kept in the liquid ignited state. There can, therefore, be no question that very considerable quantities of nitrogen gas ought to appear in the neighbourhood of such subterraneous actions on the surface of the earth. Are we to suppose that the scanty exhalations of nitrogen gas from thermal springs connected with volcanos proceed from such actions? Such exhalations are quite insignificant when compared with the formation of the masses of lava alluded to.

Professor Daubeny, however, remarks, that the nitrogen proceeding from these actions may reach the air not only in a separate condition, but also united with hydrogen in the form of ammonia. It is true, ammonia, especially sal-ammoniac, occurs among volcanic matters in craters or fumaroles, but, in general, in such small quantities as not to be sufficient to account for the huge quantities of nitrogen supposed to be separated according to the chemical theory. But, even granting all the nitrogen separated from atmospheric air to be united with hydrogen occurring in the focus of a volcano, chemists ought to ask, if a union of these gases can be supposed possible in the direct way? It is well known that chemists have hitherto been unable to unite directly these gases, even by letting down a mechanical mixture of nitrogen and hydrogen gas under the sea, to a depth of 540 metres, where the pressure is equal to 50 atmospheres. It cannot be doubted that the same laws of combination which take place in our laboratories also prevail in volcanos. But it may be replied that, for effecting combinations in the focus of a volcano, there are two powerful agents, not presented together in our laboratories, at least not in such a strong degree, viz., an enormous pressure, and heat. The former of them seems not to favour the combination of nitrogen with hydrogen, as we have above seen; and as for the latter, it is well known that ammonia is resolved into its elements by heat. Therefore, it is scarcely probable that an enormous compression in the focus of a volcano, assisted by a considerable heat, can effect a chemical combination between nitrogen and hydrogen.

However, the defenders of the chemical theory of volcanos will adduce the known fact that a mechanical mixture of hydrogen in excess, of oxygen, and of nitrogen, when ignited, produces ammonia, or rather nitrate of ammonia, and that, according to their theory, these substances ought to be present in the focus of a volcano. Supposing, for a moment, the formation of this salt, it is obvious that it would instantly be decomposed by heat into water and the protoxide of nitrogen. But, they will ask, how can you explain the occurrence of sal-ammoniac among the products of volcanic action, unless by the combination of the nitrogen with hydrogen? In reply-

ing to this question, it must be considered that many volcanos, like *Teucria*, are not with in sedimentary rocks containing organic matters, and that by their being heated, all-ammoniae is formed. Therefore, the small quantities of this salt met with in crater- or fumaroles may be sufficiently explained by supposing that rocks containing organic remains reach the focus of a volcano. In support of this I allude to the known facts, that among the masses thrown out of *Teucria*, there are not seldom large masses of limestone, which have likely occasioned the formation of all-ammoniae, and that, during volcanic eruptions, limestone shales are frequently perceived in the vicinity of the crater. Therefore, the salt just mentioned is, I think, formed in the same way in volcanos as in coal-strata which have been in a state of ignition for a long time. Thus, near *Detmold*, in the neighbourhood of *Sauerbrunn*, I have found this salt in cliffs proceeding from coal-strata which have been burning about 140 years.

In general, I by no means doubt that powerful chemical actions must take place in the focus of a volcano, in a spot where the strongest agents, such as an enormous compression and heat, are in operation. It is beyond a doubt that, under such circumstances, by the action of different substances on each other, proceeding both from the focus and from sedimentary rocks, chemical actions of the most different kind must be supposed. Therefore, each theory ought to imagine chemical changes in the focus of a volcano; but the dispute lies between the two suppositions, whether these changes are a consequence of the effects generated by the internal heat of the earth, or whether they cause them. It is only the latter supposition I contest, from considering the lava as a mass already formed in the interior of the earth. The theory suggested by myself and by many naturalists, has only to explain the rising of the lava from beneath; this is the chief question. On the contrary, all chemical actions taking place at the contact of lava with vapours, sedimentary rocks, &c., are considered by this theory only as accidental effects, affording certainly the most diversified phenomena, but without influencing in an essential manner the volcanic actions themselves. All imagined chemical changes must ensue as soon as organic

remains in sedimentary rocks come in contact with the liquid ignited matters in the focus of a volcano.

Passing from this matter, I shall turn to the supposition of an oxidation of the earthy and alkaline metals at the expense of water. Professor Daubeny alleges to my objections concerning the disengagements of enormous quantities of hydrogen in such a case, that this gas could hardly be expected to escape in a free state from a spot which contains so many elements, for which it possesses a strong affinity, and to which it would be presented under the influence of the pressure and temperature so well calculated to promote its combination with them.

Venturing to offer some remarks against these consequences, I shall first endeavour to calculate what quantities of hydrogen ought to be separated, on the supposition that a certain quantity of lava would be generated by oxidation of their metallic principles, at the expense of water. I shall then examine into the possible combinations which hydrogen may be assumed to present in the focus of a volcano.

As for the calculation, I shall found it on that given by Daubeny, above quoted. 100 parts of lava contain 42 parts of oxygen, and these are contained in 47.6 parts of water. We may consequently suppose that lava, when formed by the oxidation of its metallic principles at the expense of water, requires about 50 per cent. of it. Lava being 3.2 times heavier than water, 1 volume of the former will require about 1.5 volumes of the latter to be produced. The lava ejected from the *Skaptar Jokul* would, of course, have required a bulk of water 1.5 times as much as that of *Mont Blanc*.

I feel disposed to believe that the explanation, as to how such considerable masses of water may gain admittance to the focus of a volcano, is less difficult than the supposition that there are substances in sufficient quantity for uniting with so great an amount of hydrogen as would be separated by the decomposition of that water.

Professor Daubeny mentions the sulphur and chlorine we know to be generally present in volcanos. As 6.188 parts of hydrogen unite with 93.812 parts of sulphur to produce 100 parts of sulphuretted hydrogen, 5.6 parts of hydrogen separated

from 47.6 parts of water requisite for the oxidation of the metallic bases in 100 parts of lava, would suppose the presence of about 84 parts of sulphur. In fact, were lava to be formed in this way, and were the hydrogen separated to be united with sulphur, the quantity of the latter ought to be 84 per cent. of that of the lava generated. Applying this result for calculating the bulk of sulphur requisite for producing the lava ejected from *Skaptar Jokul*, we find this bulk about 1.4 times as much as that of *Mont Blanc*, for the specific gravity of sulphur is 1.99, and that of lava 3.2. Indeed, such a considerable quantity of sulphur can scarcely be assumed in the focus of a volcano. But even let us suppose it, on the other hand it must be asked, how comes it that the earthy and alkaline metals, having a strong affinity to sulphur, are not rather united with this substance? Though these combinations do not take place at a common temperature, yet they were to be expected, as soon as heat is evolved by the commencing oxidation of the metallic bases, at the expense of water or atmospheric air. Therefore, the advocates of the chemical theory cannot suppose the presence of sulphur in the focus itself, where these metals are imagined to be, but in higher places, where the hydrogen arising from beneath would unite with it. Granting even the sulphur to be in these higher places, the formation of sulphuretted hydrogen, nevertheless, cannot be supposed, as it is known that hydrogen and sulphur cannot be united directly, and scarcely even by melting and volatilizing sulphur in hydrogen gas.

Finally, it must be well considered that, according to the chemical theory, the decomposition of water by metallic principles would be the first phasis of volcanic action; that, consequently, the second one would be the combination of the hydrogen separated with sulphur. These two phases of volcanic action would of course precede by a long period the eruptions of lava. But volcanic phenomena present, in general, the contrary of these suppositions. Disengagements of sulphuretted hydrogen gas do not take place before the issuing of lava, but, for the most part, after all other volcanic phenomena having ceased. It is well known that these disengagements take place, in general, when a volcano is in the state of a sol-

fatara. The solfatara near *Puzzuoli*, and many in the *Andes*, present sufficient instances of this kind.

This circumstance seems to me the most fatal to the chemical theory. I cannot imagine how its advocates can remove this difficulty. They will not surely be disposed to assume that the hydrogen separated by the decomposition of water, in the first phasis of volcanic action, is reserved in vast caverns near and about the focus of the volcano, and that it is only a long time afterwards that the combination with sulphur takes place?

I am quite at one with Professor Daubeny, in admitting the large beds of sulphur which exist in most volcanic districts (*viz. Sicily*), to be the result of the decompositions of the sulphuretted hydrogen evolved. Many years ago I stated in German journals, and, I think, on good grounds, that these beds, both in volcanic and neptunian districts, may for the most part have been generated by the slow oxidation of sulphuretted hydrogen at the common temperature, at the expense of atmospheric air, whereby only the most oxidisable ingredient of it, the hydrogen, was oxidised, whilst sulphur was deposited. Regarding the formation of sulphuretted hydrogen, there is, however, a difference of opinion between Daubeny and myself. He remarks, that I pass over without any attempt of explanation, among other things, the evolution of sulphuretted hydrogen, in quantities far exceeding what are to be explained by the reaction of carbonaceous matter upon sulphates, or any of those other processes which sometimes produce it on the surface of the earth.

Though intending to discuss this subject in my future publications, yet I may take this opportunity of answering these remarks of Professor Daubeny.

Sulphuretted hydrogen seems generally to be formed by the reaction of carbonaceous matter upon sulphates. There are many instances which appear to lend considerable weight to this supposition. Thus mineral waters containing sulphates disengage sulphuretted hydrogen, when for a long time in contact with any organic matter, for instance straw. I once put a tea-spoonful of sugar in such a water, placed in a pitcher. After having allowed it to remain four years in a cellar, such a considerable quantity of sulphuretted hydrogen was gene-

rated as to form a strong sulphurous water. The sulphate of soda formerly contained in it had disappeared, and iron pyrites was deposited. On the bottom of a mineral spring containing only a very small quantity of sulphate of soda, I once found pieces of iron pyrites, including organic matters, such as branches and stalks of plants. There is no doubt but this iron pyrites was formed by the decomposition of sulphate of soda and carbonate of the protoxide of iron, at the expense of the organic matter.

We can accordingly have no difficulty in admitting most sulphurous springs to be formed in the same way. In support of this, it may be mentioned, that all sulphurous springs contain sulphates and organic matters. I allude only to those in the *Pyrenees*, which, it is known, abound in vegetable matter, the so-called *Baregine*.

Many exhalations of sulphuretted hydrogen in volcanic districts may be formed in the same way. At least organic matters are not wanting in sedimentary rocks which have been broken through by volcanic actions, and sulphates exist in many volcanic products.

Assuming that melted lava comes in contact with sulphur at any part of a volcano, and that the so-called liver of sulphur is produced from alkalis and alkaline earths; supposing, farther, that the liver of sulphur meets with water and carbonic acid gas, sulphuretted hydrogen will be evolved. We may easily imagine exhalations of this gas during the course of many ages, when liver of sulphur abounds. Indeed, the immense disengagements of carbonic acid gas in many districts of former volcanic action, within the memory of man, appear to lend considerable weight to the theory suggested.

I shall not pass from these considerations without alluding to Daubeny's supposition that the chlorine also, which we know to be generally present in volcanos, may be united with the hydrogen evolved by the decomposition of water. But the occurrence of a considerable quantity of chlorine in a free state in a volcano is hardly probable. We know this substance to be merely evolved when a peroxide is present. In the interior of the earth there is only that of manganese which is rather abundant. When present at the locality of a volcano,

it can merely be supposed to exist in such places where there is no red heat. An enormous quantity of chlorine must be present to unite with the hydrogen evolved. For instance, 5.6 parts of hydrogen, calculated above, require 187 parts of chlorine to be present for producing 100 parts of lava, when the hydrogen separated from water is to unite with it.

Whatever be the importance of these reflections, every one must come to the conclusion, that the production of lava, by oxidation of its metallic principles, requires immense quantities of atmospheric air or water, and that the hydrogen separated by the decomposition of water, supposes the presence of sulphur or chlorine for uniting with them in such quantities as to exceed those of the lava itself.

It is true, the quantities of gaseous matters rising from the crater of a volcano during its eruption cannot be estimated in proportion to the lava issuing from it at the same time. However, as soon as these matters should exceed the lava in quantity, the atmospheric air round about the volcano, to a considerable distance, would be quite fatal to animal life. Accounts of the eruptions of *Vesuvius* and other volcanos do not mention such phenomena. Gaseous exhalations, it is true, take place in abundance in the environs of *Vesuvius*, but only after the cessation of the eruption and the issuing of lava. These exhalations, consisting of carbonic acid gas, cannot be connected with oxidations of the metallic bases supposed to exist in the interior. Professor Daubeny himself assumes that these disengagements cannot be derived directly from chemical processes which produce the phenomena supposed by him, but that they are only caused by the heat which these processes tend to diffuse through the adjacent rocks.

Among the simple bodies for which hydrogen possesses a strong affinity, oxygen occupies a high rank. Professor Daubeny speaks of this gas uniting with the hydrogen separated by the decomposition of water. However, it seems to me rather difficult to suppose its presence in a place where, according to him, mighty oxidations take place. But even granting atmospheric air, after having acted upon the metallic principles, to reserve a sufficient quantity of oxygen for the ignition of the hydrogen evolved, this supposition leaves the explanation gene-

rally on the same footing. Indeed, admitting this, it is the same as if atmospheric air alone were to oxidise the metallic principles of lava, viz. the same quantity of oxygen, formerly furnished to them by water, must now be afforded to the hydrogen by the atmospheric air.

To these considerations it may be added, that Sir Humphry Davy could not, in any of the several instances in which he experimented on lava, when freshly poured out, and in a liquid ignited state, detect any traces of pure or uncombined alkaline or earthy inflammable bases.* Dr John Davy properly adds that the absence of iron in its metallic state amongst the products of volcanos, so abundantly oxidated in the first degree of oxidation, is very unfavourable to the idea that large quantities of inflammable gas are evolved in volcanic eruptions, or even disengaged. Were this oxide acted on by hydrogen at a high temperature, what is there which could prevent its decomposition? and if reduced, we might expect to discover it in this state, at least occasionally, enveloped in and protected by lava.

Before finishing my remarks, I cannot help asking the defenders of the chemical theory, whether they suppose that the volcanic actions by which the immense mountains of granite, trachyte, basalt, porphyry, &c., have been elevated, resulted from the same chemical processes? The question is, did these masses occur in the interior of the earth in a metallic condition, or as oxidised bodies? In the latter case the advocates of that theory would be obliged to embrace the very same explanation of volcanic actions I am venturing to defend. On the contrary, by assuming the former opinion, the very same difficulties would be placed in opposition which I have established above, but, as we cannot doubt, only much greater in degree. It must be asked where are to be found the substances separated by the oxidation of the metallic bases of the liquid ignited masses that have arisen from the interior, whether it was that atmospheric air or water was decomposed, whether it was that nitrogen or hydrogen was separated, or that ammonia, or sal-ammoniac, or sulphuretted hydrogen was produced? These substances, the equivalents of the ejected liquid

* *Memoirs of the Life of Sir Humphry Davy, by his brother, vol. ii. p. 122; and Collected Works, vol. i. p. 259.*

ignited masses raised up, amount to quantities equal to the volcanic rocks, and even surpassing them, as we have seen above. But nowhere on the surface of the earth, or in the atmosphere, are such immense masses found. If the defenders of such a hypothesis were to suppose that in former times the proportion of oxygen in the atmospheric air was greater than now, the possibility of such a supposition cannot be denied without hesitation ; however, it may be remarked, that there are other grounds for inferring the opposite opinion.

INDEX.

1

INDEX.

- Air*, analysis of its water, 84.
Air, its influence on observations of temperature in mines, 121-124.
Arragonite is deposited from hot springs, 230, 238.
Artesian wells, their temperature, 5, 191.
Aspronisi, 239.
- Banda Islands*, 242,
Basalts, their occurrence, 237, 239.
Bogota, earthquake, 255.
Bornholm, elevation, 249, 254.
- Calcareous spar* is deposited from cold springs, 230.
Calmar, elevation, 249.
Carbonic acid gas disengaged from chalk by sulphuric acid and by heat, 9—its evolution from acidulous springs, 13—passing through hot springs, 14—exhalations, 204—in the district of the Laacher See, 280—give evidence of former volcanic action, 230—decompose volcanic rocks, 286.
Chili, elevations there, 246, 248, 251.
Chlorides cannot be considered as the chief agents in volcanic phenomena, 207.
Chthonisothermal lines, 130—their rising in mountains, 131—their inclination to the horizon, 132—their curves in all mountains, 136—their maximum angle in mountains having a perpendicular ascent, 137—their sinking under the sea, lakes, and glaciers, 138.
Climate, its influence on the progression of the increase of temperature towards the interior, 124, 125.
Cones, basaltic, porphyritic, and granitic, connected by rents, 222.
Craters of eruption, 245—of elevation, 239, 245.
Cumana, elevation there, 246.
- Dalmatian coast*, sinking, 250.
Dislocations in the Alps, 94.
- Earthquakes* explained by the internal heat of the earth, 209—closely connected with volcanic phenomena, 255, 256—do not coincide with volcanic eruption, 257—take place at a great depth, 255—caused by the effort of elastic fluids, 256-258—by the sinking of rocks in the interior, 263—accompanied with exhalations of gas, 259, 261—with bursting forth of flames, 259-261—the shocks follow the direction of chains of mountains, 258—stones and water emitted from vents during earthquakes, 260—smoke, 261—elevation of the temperature of the sea, 261—their propagation is not confined to any particular rock, 261—follows the direction of the rocks, 262—of the basaltic masses, 262—in all directions, 262—originate from a common centre, 263—-independent of external circumstances, 265—cause changes in the hot springs of Iceland, 229—cause elevations, 246, 247—Earthquake caused by the penetration of a large mass of melted iron into the soil, 258.
Eruptions, submarine, 232.
- Flames*, never seen from the crater of Vesuvius, 203.
Finland, the gradual elevation of, 248, 254.
Firn, 69.
- Gandecken*, 91.
Geyser, 226-229.
Glaciers, the melting of, from underneath, 65-69—by means of springs, 76, 83—by means of air, 88—quantity of ice melting away from them, 70—currents of air in the channels of them, 86, 89—accumulations of water below them during the winter, 81—retain in their interior no foreign matter, 70—temperature of the soil

- under them, 71, 75, 89—causes why this temperature is higher than 32° , 72—formation of the holes in them, 73—the increase and decrease of glaciers, 90—causes acting in opposition to the increase, 91—cause a depression of temperature in their environs, 144—observations on this near the lower glacier of Grindelwald, 144—146—glacier streams flow also in winter, 78—their contents of fixed substances must be different in different seasons, 81.
- Gonung Api*, 242.
- Granites*, their occurrence, 237, 239.
- Greenland*, sinking, 250.
- Gufferlinten*, 81.
- Heat*, internal, of the earth, progression of its increase, 185–210—how the most accurate results are to be obtained, 189—cannot be with certainty deduced from the temperature of Artesian springs, 191—rising through clefts in the Jura limestone, 289—elevates the temperature of all fissured chalk hills, 293.
- Herculanum*, 244.
- Hiera*, 240.
- Hills*, rising on rents, 222.
- Hydrogen Gas*, seems never to issue from volcanos, 202.
- Ice-Grottos*, their influence on observations of temperature in the earth, 124.
- Jorullo*, its elevation, 243.
- Iron-Glance*, its formation during volcanic eruptions, 206.
- Islands*, their frequent elevation from the bottom of the sea, 239.
- Isogeothermal and Isothermal Lines* coincide in general, 44.
- Isothermal Lines*, subterranean, 130.
- Kameni*, 240.
- Lakes*, decrease of temperature in them, 97—their temperature at considerable depths, 98—its excess is due to the warmth of the interior, 102—rising and descending currents in lakes, 102–104—they receive the more heat, the hotter the climate and the deeper they are, 104—the mean temperature of their surface seems to be higher than that of the soil in their vicinity, 106—the deeper they are, the later will, during the winter, their surface be reduced to the freezing point, 107—elevated Alpine lakes may freeze to the bottom in winter, 109.
- Lancarote*, 242, 231—elevation there, 246.
- Lava*, its fusibility, 209—at what depth in fusion, 210—its quantity is commonly inversely as the height of the fissures from which it issues, 219—how it may be elevated from beneath, 219—differs in its characters, 222—enormous quantities brought up, 232, 233—formation of, 201, 231.
- Leuckerbad*, origin of, 148.
- Limestones*, their conversion into marble, 237.
- Lisbon*, earthquake at, 246, 255.
- Lütschine*, chemical examination of, 84.
- Matters*, melted, in the interior of the earth, their consolidation produced by crystallization, 220, 238—their rising out of the interior, 236—through the bottom of the sea, 239—alterations in adjacent rocks produced by matters forced up, 237.
- Metals* of alkalies and earths converted into lava by oxidation, 201, 231.
- Mocha*, elevation of, 248.
- Mofettas*, the temperature of, 13, 203.
- Molucca Islands*, 241—elevation, 248.
- Monte Nuovo*, its elevation, 243, 244.
- Monte Rosso*, its elevation, 243.
- Monte Somma*, 244.
- Moraines*, 91.
- Moto vorticoso*, 261.
- Moya*, 260.
- Muriatic acid gas* is not evolved from the volcanos under the equator in the New World, 203—but from Vesuvius, 205.
- Nitrogen gas* is not evolved from volcanos under the equator in the New World, 203.
- Ochotsk*, earthquake at, 255.
- Otaheite*, elevation of, 248.
- Plants* do not possess a warmth of their own, 99.
- Plutonic masses* and Neptunian formations, relations between them and thermal springs, 285.
- Pompeii*, 244.
- Porphyries*, their occurrence, 237.
- Reservoirs*, subterranean, of water, in the chalk-hills of the Teutoburger Wald, 290—proofs of their great extent, 291, 293.

Rhine, analysis of its water, 84—quantity of water carried by it out of Switzerland, 70—quantity of solid matter annually carried out, 92.

Rocks, their unequal power of conducting heat causes differences in the progression of temperature towards the centre of the earth, 125–127;—*crystalline*, their fusibility, 209—*trap*, their occurrence, 237—*unstratified*, proofs of their pyrogenetic origin, 238—of very different natures, are often met with close to each other, 223—in close contact with all the stratified and superficial formations, 236—form dykes in the stratified rocks as well as in one another, 236.

Sabrina, 241, 243.

Salt, common, in lavas, 206—seems not to be general, 207.

Santa Maria, elevation, 248, 251.

Santorin, 239, 240.

Scandinavia, the gradual elevation of, 248, 251, 253, 254.

Scotland, elevations there, 247.

Sea, its temperature at various depths, 98 and foll.—must receive heat from the earth beneath, 111—temperature of its surface decreases on approaching land or shallows, 112—this phenomenon is not dependent on the latitude, 113—the mean temperature of the surface of the sea is higher than that of the surrounding atmosphere, 113, 116.

Seas and lakes, having a great depth immediately near shore, produce on it a depression of temperature, 142—observations on the shores of the lakes of Thun and Brienz, 142, 143.

Siberia, Northern, the frozen soil of, 95—is not contradictory to the supposition of a state of fusion in the interior, 96.

Sismograph, 257.

Snow, perpetual, limits of, 151.

Springs, acidulous, their elevated temperature is not occasioned by the absorption of carbonic acid gas, 8—do not always exceed fresh-water springs in temperature, 14, 15—of fresh water in the vicinity of the glaciers and on the limits of perpetual snow, their temperature, 27—rising out of limestone rocks, the amount of carbonate of lime they contain, 86—*hot*, come up under glaciers, 77—at Leuckerbad, 77—in the Alps, 277, 278—serve as a protection against earthquakes, 267—closely connected with volcanic

action 223, 224, 225, 267—especially in Iceland, 226, 229—chemical processes cannot be the cause of their being heated, 16–20, 268, 269—the action of electrometers also not, 21—internal heat alone, 20, 268, 270—also volcanic masses elevated, 270—*hot-test* in Europe, 224—*hot and thermal*, definition of, 2, 268—containing the greatest quantity of fixed substances, are not always the hottest, 18—alteration of their temperature, 225—and chemical composition during earthquakes, and in the vicinity of active volcanos, 22, 23—causes of this phenomenon, 24, 27—occurring at the point of intersection of the two different systems in the Alps, 277—in other places, 283—*intermitting* caused by the existence of caverns, 228—*mineral*, exceed the mean temperature of the place, 2–8—also many fresh water springs, 3—in the district of Laacher See, their origin, 279–282—*mountain*, are not capable of giving the decrease of temperature in the ground with the height, 76—*saline* without sulphate of lime, 287—*sulphureous*, their origin, 287—in secondary rocks in the Pyrenees, 275—*thermal*, are to be found in all formations, in all latitudes, and in the most different heights, 7, 8—in the Alps are ordinary warm waters, 278, 287—can participate in the variations of the external temperature, 33, 57—their number may probably surpass that of the cold ones, 37, 38—their influence on the temperature of the interior, 119–121—relation between them and Plutonic masses and Neptunian formations, 285—obtained by boring, 282, 283—their chemical ingredients, 286—*warm*, rising at the foot of high mountains, their origin, 148.

Springs descending from great heights bring down cold with them, 28–31, 32—their variations of temperature seldom keep an equal pace with that of the air, 31, 32—their extent of the yearly differences of temperature, 33—the line can hardly be drawn between mineral and fresh-water springs, and between warm and cold ones, 34, 35—springs of constant temperature must always be considered as thermal, 33, 39—rising out of loose stones are invariably colder than those coming from solid rock, 41—their temperature is a function of that of

ERRATA.

Page 44, line 4 from the top, for *are grounds* read *are no grounds* Page 54 line 26, for *Wetter* read *Wetter* Page 54, line 27, insert *are* before *another*, and also *and form a* after *another* Page 66, line 15, for 36° 45' read 36° 23' Page 66, line 21 for 46° 57' read 12° 57' Page 68, line 23, for 41° 55' read 5° 55' Page 68, line 1, for 38° 51' read 1° 51' Page 67, line 34, for *Lochrow* read *Lochrow* Page 68, line 34, insert nearly after *is* Page 76, line 24, for *coldest* read *coldest* Page 77, line 34, for *Dunbarre* read *Dunbarre* Page 77, line 36, for *Loumery* read *Loumery* Page 83, lines 25 and 27, put the clause, *at this season the day*, in parentheses Page 83, line 27, for 1000 read 10,000 Page 83, line 84, in the analysis of the water of the Aar and Rhine the numbers 0.00287 and 0.01688 are the quantities of the chloride of sodium and potassium Page 105, line 13, for 47.72 read 41.72 Page 105, line 23, for 9.72 = 38° 42' read - 41° 72' = 38° 42' Page 105, line 23, for *Schaeffer Seidel*, as above p. 36, read *loc. cit.* p. 36 Page 106, line 26, for 7° 30' read - 8° 3' Page 111, line 20, for 35° 36' read 5° 36' Page 112, line 31, for 2° 50' read 38° 73' Page 124, line 7 from the bottom, for 0° 047 read 0° 104 Page 125, line 3 from the top, for 0° 225' read 0° 225' Page 124, line 7, for 347 read 24.7 Page 144, line 13, for 37° 35' read 5° 35' Page 144, line 14, for 36° 36' read 4° 36' Page 144, line 14, for 41° 34' read 9° 34' Page 144, line 14, for 4° 38, making read 4° 38, making Page 144, line 17, for 8° 76' read 8° 77 Page 147 line 1, for *e* the read *to* Page 153, line 23, for 15° 75' read 15° 3 Page 155, line 17, for 6° 20' read 6° 35' Page 155, line 23, for 4° 41' read 5° 42' Page 167, line 1, for 38° 34' read 37° 51' Page 173, No. v., line 1 from the bottom, for 48° 45' read 47° 45' Page 173, No. viii., line 7, for 54° 48' read 32° 35' Page 173, No. xvii., line 3, for 46° 45' read 44° 5 Page 173, line 11 from bottom, for 32° 35' read 31° 44' Page 184, line 29 from bottom, for 0° 534' read 0° 56 Page 184, line 26 from bottom, for 0° 391 read 0° 395 Page 184, line 25 from bottom, for 0° 225 read 0° 47 Page 181, line 20 from the top, for 66° 70' read 67° 70 Page 181, line 20 from the top, for 66° 70' read 67° 70 Page 181, line 23, for 22° 36' read 53° 47 Page 186, line 28, for 2° 25, 2° 25 - 4° 4 F. read 2° 25 Page 186, line 29, for 122 - 67 read 115 Page 186, line 4, for 60° 23 read 60° 44 Page 194, line 24, for 56° 37' read 54° 7 Page 194, No. xviii., June, for 48° 57' read 48° 79 Page 194, No. xxviii., February, for 48° 58' read 47° 28 Page 194, number of page, for 122 read 193 Page 194, No. xxxiv., March, for 46° 03' read 47° 08 Page 194, No. xxxiv., Differ. for 7° 18 read 7° 39 Page 194, No. xxxvi., June, for 57° 43' read 54° 43 Page 194, No. xliii., March, for 48° 45' read 46° 4 Page 194, No. li., May, for 48° 45' read 46° 4 Page 194, No. li., November, for 48° 44' read 49° 44 Page 194, No. li., mean, for 56° 95' read 48° 50 Page 194, No. li., July, for 49° 01' read 48° 92 Page 194, No. li., August, for 49° 01' read 48° 92 Page 197, No. li., January, for 43° 02' read 42° 42 Page 197, No. li., April, for 47° 97' read 47° 37 Page 197, No. lxi., February, for 34° 77' read 34° 47 Page 197, No. lxi., January, for 36° 7' read 26° 56 Page 197, No. lxi., December, for 47° 44' read 37° 44 Page 197, No. lxi., January, for 39° 32' read 40° 32 Page 197, No. lxi., September, for 55° 51' read 56° 41 Page 197, No. lxi., March, for 37° 58' read 38° 7 Page 204, line 16, from the top, for *part* read *heat* Page 204, line 11, for *carbonate* read *carbonic*

The titles above the pages from 57 to 193 may be corrected according to the titles of the chapters.

There is only one plate illustrative of the volume; and in the reference to it at p. 87, the words "Plate I." ought to have been left out, while in the references to it at p. 120, 121, 130, 132, 133, 135, 136, 139, 146, "Plate II." ought to have been left out.









